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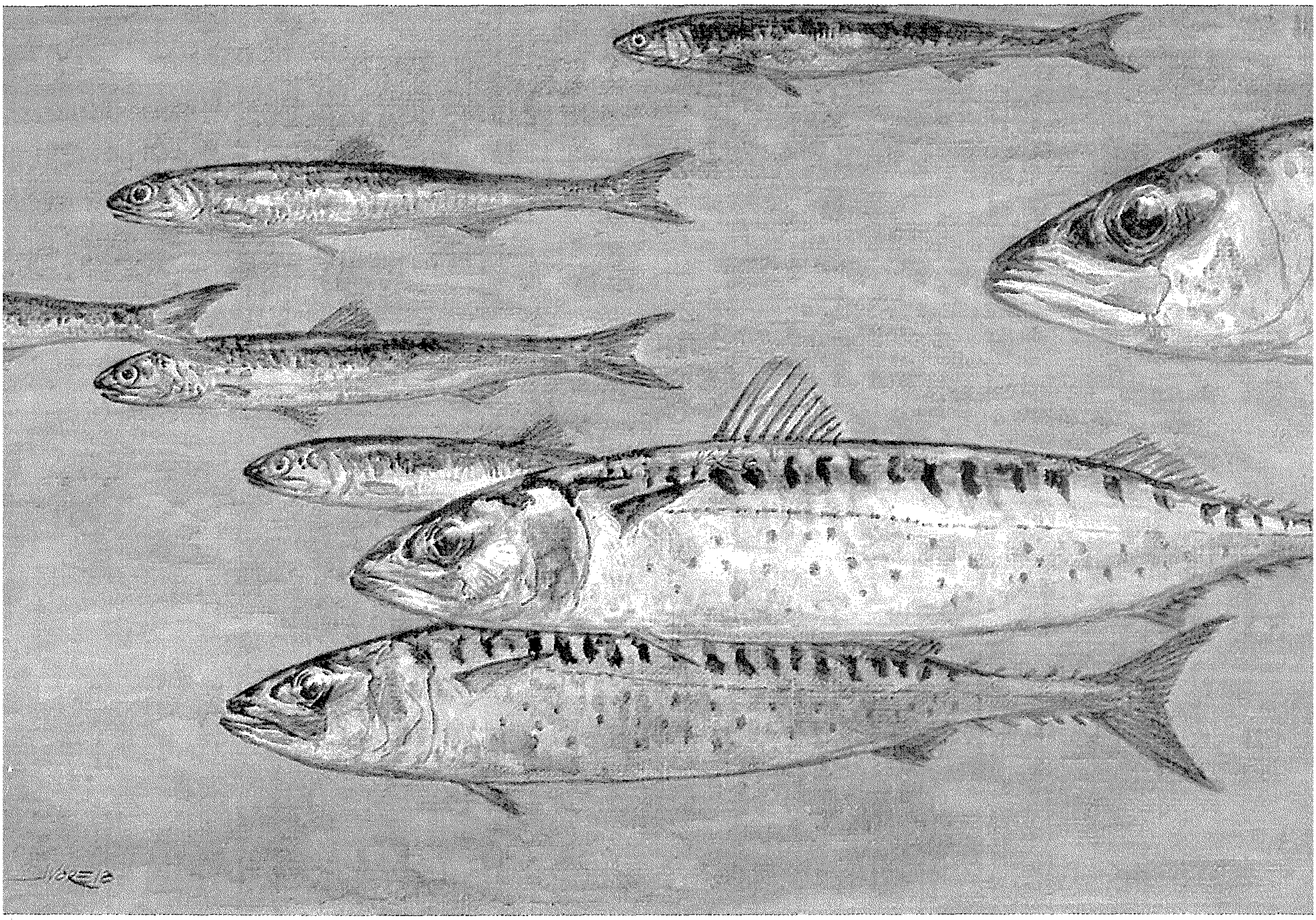

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SYNOPSIS OF BIOLOGICAL DATA ON THE CHUB MACKEREL (*Scomber japonicus* Houttuyn, 1782)

Prepared by
José J. Castro Hernández
and
Ana T. Santana Ortega
Departamento de Biología
Universidad de Las Palmas de Gran Canaria
Apdo. 550, Las Palmas de Gran Canaria, Spain

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PREPARATION OF THIS SYNOPSIS

The chub mackerel *Scomber japonicus* is a very important species in commercial and artisanal fisheries throughout the world. Although it is heavily fished and detailed fishery information is available, this is the first time biological data and fishery information is brought together by the authors in a single edition. As quantitative and qualitative information of various aspects of the biology, ecology, stocks and utilization of the chub mackerel is widely scattered in the literature, this synopsis was undertaken to fill the need for comprised and detailed information on this important scombrid to help to improve the knowledge about this species and to maintain it as an important food resource for human consumption.

ACKNOWLEDGEMENTS

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Project Manager: P. Oliver (FAO, Rome).

Technical Editors: R. Bonfil (University of British Columbia, Canada), J. Minow (FAO, Rome).

Illustrators: P. Lastrico, E. D'Antoni (FAO, Rome) and J. Varela.

Page Composition: M. Kautenberger (FAO, Rome).

Maps: F. Carocci (FAO, Rome).

Contact Address: Tel: 34 928454549; Fax: 34 928452922; E-mail: josejuan.castro@biologia.ulpgc.es

Castro Hernández, J.J.; Santana Ortega, A.T.

Synopsis of biological data on the chub mackerel (*Scomber japonicus* Houttuyn, 1782).

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ABSTRACT

Chub mackerel (*Scomber japonicus*) is a pelagic species that inhabits warm and temperate coastal waters of the Atlantic, Indian and Pacific Oceans. Chub mackerel undertakes considerable seasonal migrations between feeding and spawning areas. This species reaches its fastest growth in length (between 35.4 and 62.6% of the maximum length of the species in each area) during the first year of life. The maximum reported age is 18 years. Spawning is normally limited to the first half of the year in the northern hemisphere, and to the second half in the southern hemisphere, but spawning takes place all year round around the equator. Chub mackerel feed on zooplankton, although cephalopods and small pelagic fishes, especially anchovies and sardines, are also frequent in the diet. There is also evidence of cannibalism in this species. Chub mackerel are frequently preyed by tunas, marlins, sailfish, dolphin-fish, sharks, sea lions and sea birds. This species is of great importance for fisheries worldwide. In 1978, the chub mackerel ranked third in importance in catches by species (3.4 million tons), while in 1979 and 1980 it ranked fourth and fifth, with 2.8 and 2.6 million tons, respectively. In 1966 this species ranked fifth with a worldwide catch of 2.1 million tons. It is mainly caught with purse seines, sometimes using light, and also by trolling, lines, gillnets, traps, beach seines and midwater trawls.

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1. IDENTITY

1.1 Nomenclature

1.1.1 Valid name

The scientific name for the chub mackerel is ***Scomber japonicus*** (Houttuyn, 1782) (Fig. 1).

1.1.2 FAO Code

1.75 (01) 001.01

1.1.3 Synonyms

Scomber japonicus japonicus Houttuyn, 1782
Pneumatophorus japonicus japonicus Houttuyn, 1782
S. japonicus: Bonnaterre, 1788
S. colias Gmelin, 1789
S. japonicus colias (Gmelin, 1789)
S. pneumatophorus Delaroche, 1809
S. colias: Rafinesque, 1810
S. macrophthalmus Rafinesque, 1810
S. grex Mitchill, 1815
S. grex: Cuvier, 1829
S. pneumathophorus: Cuvier, 1829
S. capensis Cuvier, 1831
S. maculatus Couch, 1832
S. undulatus Swainson, 1839
S. gracilis Swainson, 1839
S. macrophthalmus: Bonaparte, 1845
S. saba Bleeker, 1854
S. janesaba Bleeker, 1854
S. dekayi Storer, 1855
S. diego Ayres, 1857
Pneumatophorus diego (Ayres, 1858)
S. janesaba: Günther, 1860
P. japonicus Starks, 1922
P. colias Starks, 1922
P. grex Jordan & Hubbs, 1925
P. diego Jordan & Hubbs, 1925
P. peruanus Jordan & Hubbs, 1925
S. japonicus peruanus Jordan & Hubbs, 1925
S. gigas Fowler, 1935
P. japonicus marplatensis López, 1955
S. japonicus colias Padoa, 1956
S. japonicus marplatensis (Sánchez, 1959)
P. peruanus: Kramer, 1960
S. peruanus Fitch & Craig, 1964
S. diego: Fitch & Craig, 1964
S. (Pneumatophorus) japonicus: Lloris, 1986.

1.2 Taxonomy

1.2.1 Affinities

1.2.1.1 Suprageneric

Kingdom:	Animalia
Phylum:	Chordata
Subphylum:	Vertebrata
Superclass:	Pisces
Class:	Osteichthyes

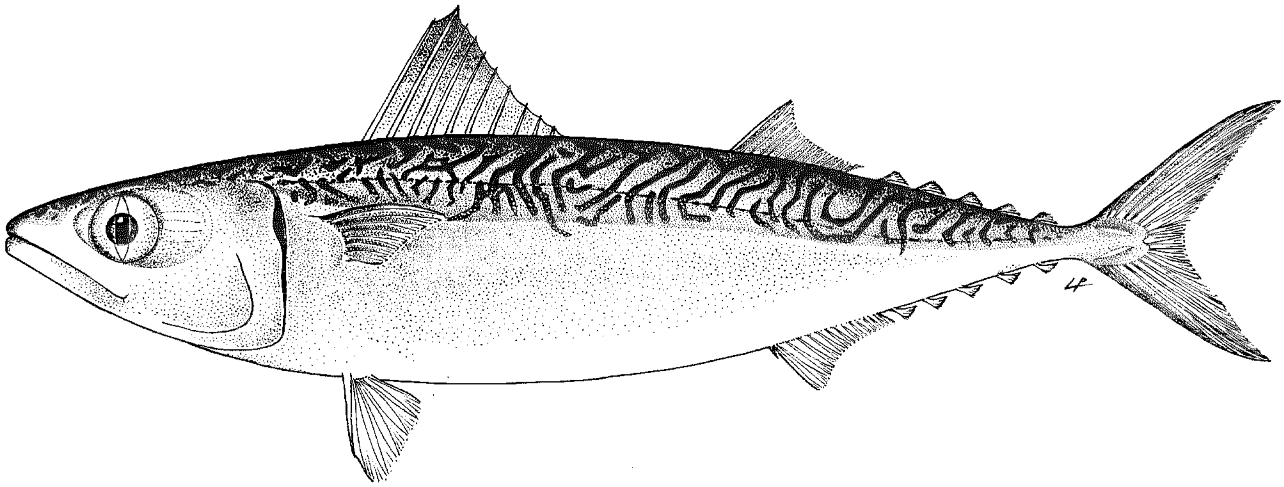


Figure 1. Chub mackerel (*Scomber japonicus* Houttuyn, 1782)
(from Collette & Nauen, 1983)

Subclass:	Neopterygii
Order:	Perciformes
Suborder:	Scombroidei
Family:	Scombridae
Subfamily:	Scombrinae
Tribe:	Scombrini
Genus:	***Scomber***

1.2.1.2 Generic

In 1847, the Count of Buffon reported that the "escombro of Japan" (the chub mackerel) was possibly a variety of the "mackerel escombro" (***Scomber scombrus***), as professor Gmelin suspected. He also reported that this species reached a maximum length of 20 cm and inhabited the Sea of Japan.

The subfamily Scombrinae, belongs to the family Scombridae and is composed of two groups with two tribes each. The first group comprises the tribes Sardini and Thunnini, and the second and more primitive group is composed of the tribes Scombrini and Scomberomorini (Collette & Nauen, 1983). The tribe Scombrini contains two genera of mackerels, ***Scomber*** and ***Rastrelliger***. The characteristics distinguishing both genera have been given by Matsui (1967).

- Diagnosis

Body elongate and rounded. Snout pointed. Front and hind margins of eye covered by an adipose eyelid. Entire body covered with rather small scales; scales behind head and around pectoral fins larger and more conspicuous than those covering rest of body, but not well developed corselet. Gill rakers shorter than gill filaments, barely visible through open mouth; 25 to 35 gill rakers on lower limb of first arch. Two widely separated dorsal fins, the first with 8 to 13 spines, second dorsal and anal fins with 12 rays; anal spine fairly stiff and strong; 5 dorsal and 5 anal finlets; interpelvic process small and single; pectoral fin short, with 18 to 21 rays. Two small keels on each side of caudal peduncle (at base of caudal fin lobes), but no central keel between them. Teeth in upper and lower jaws small and conical; teeth also present on vomer and palatine bones. Swimbladder present or absent. Vertebrae 31. Last branchiostegal ray slightly flattened but not forming a wide plate (Collette & Nauen, 1983).

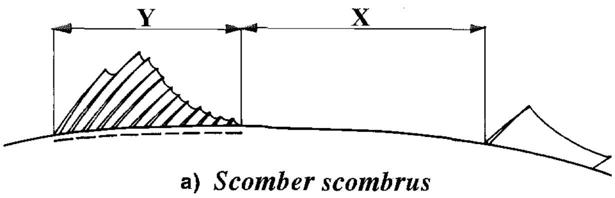
1.2.1.3 Specific

Three species of ***Scomber*** are herein recognized: ***S. scombrus*** Linnaeus, 1758 (Atlantic mackerel), ***S. japonicus*** Houttuyn, 1782 (chub mackerel), and ***S. australasicus*** Cuvier, 1831 (spotted chub mackerel).

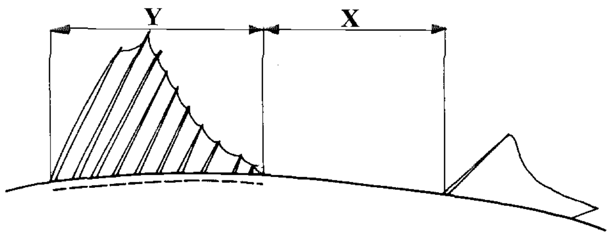
- Specific diagnosis

1a. Space between end of first dorsal fin groove and origin of second dorsal fin (x) greater than length of groove (y), about 1.5 times as long (Fig. 2a); swimbladder absent; belly unmarked; 13 precaudal plus 18 caudal vertebrae; 21 to 28 interneural bones under first dorsal fin. . . . . ***Scomber scombrus***

1b. Space between end of first dorsal-fin groove and origin of second dorsal fin (x) about equal to or less than length of groove (y) (Fig. 2b); swimbladder present; belly unmarked or marked by spots or wavy broken lines; 14 precaudal plus 17 caudal vertebrae; 12 to 20 interneural bones under first dorsal fin



a) ***Scomber scombrus***



b) ***Scomber japonicus***

Figure 2. Space between end of first dorsal-fin groove and origin of second dorsal fin (x) and length of groove (y)

(from Collette & Nauen, 1983)

2a. First dorsal-fin spines 9 or 10; distance from last dorsal spine to origin of second dorsal fin (x) less than distance between first and last spine (y) (Fig. 3a); 12 to 15 interneural bones under first dorsal fin . . . ***Scomber japonicus***

2b. First dorsal fin spines 10 to 13; distance from tenth dorsal spine to origin of second dorsal fin (x) greater than distance between first to tenth spine (y) (Fig. 3b); 15 to 20 interneural bones under first dorsal fin . . . . .
. . . . ***Scomber australasicus***

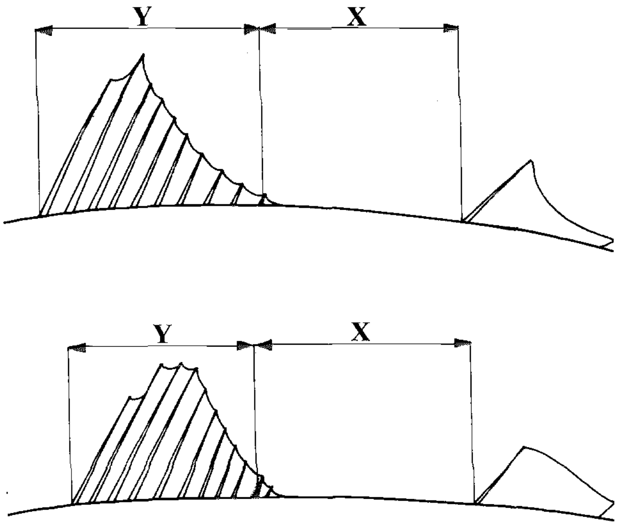


Figure 3. Distance from last dorsal-fin spine to origin of second dorsal fin (x) and distance between first and last dorsal spine (y)

(from Collette & Nauen, 1983)

1.2.2 Taxonomic status

S. scombrus differs in having more heavily ossified bones, in lacking a swimbladder, and having the first haemal spine previous to the first interhaemal bone. However, the many similarities between ***S. scombrus***, ***S. japonicus***, and ***S. australasicus*** indicate that they should be placed in the same genus, and that there is no reason to recognize ***Pneumatophorus*** for the latter two. The number and arrangement of the interneural bones under the first dorsal fin is one of the most useful characters for distinguishing the species of ***Scomber*** (Matsui, 1967).

Scomber scombrus is abundant in temperate waters of the North Atlantic Ocean, and it is an economically important species in this area. It is also frequent in the Mediterranean and Black Seas. ***S. australasicus*** is found in waters of the southeast Pacific Ocean, Australia and Tasmania. It is frequent in Hawaii and in the eastern Pacific Ocean near Mexico (Matsui, 1967). According to Baker & Collette (1998) it is also present in the Red Sea and in the northern Indian Ocean (Gulf of Aden and Oman).

Scomber japonicus is a temperate-water species, but generally in warmer areas than ***S. scombrus***. Populations of ***S. japonicus*** from the Pacific, western Atlantic and eastern Atlantic, show recognizable differences below the species level (Matsui, 1967).

1.2.3 Subspecies

No information available to the authors.

1.2.3.1 Standard common names, vernacular names

Country	National names
Albania:	Skumber
Algeria:	Macarelli
Argentina:	Caballa, magru
Australia:	Chub mackerel, common mackerel
Brazil:	Cavalinha, caballa
Bulgaria:	Skumrija
Canada:	Chub mackerel, maquereau blanc, Pacific mackerel
Chile:	Caballa
Colombia:	Caballeta, salmonete
Corsica:	Strumbulu
Croatia:	Lokarda, lancarda, plavica
Cuba:	Caballa
Cyprus:	Scoumbri
Denmark:	Spansk makrel
Djibouti:	Maquereau espagnol
Ecuador:	Caballa, macarela, morenillo
Egypt:	Kaskomri, scomber
Finland:	Japaninmakrilli, Espanjanmakrilli
France:	Maquereau espagnol, bis, vizet, maquereau blanc, hareng du pacifique
Germany:	Spanische Makrele, Blasenmakrele, Mittelmeermakrele, Thunmakrele, Japanische Makrele
Great Britain:	Spanish mackerel, big-eyed mackerel, chub mackerel, Pacific mackerel, scomber
Greece:	Koliós
Guatemala:	Caballa
Hawaii (USA):	Opelu palahu, saba
Iceland:	Spánskur makrill
India:	Chub mackerel
Ireland:	Spanish mackerel
Israel:	Kolias
Italy:	Lanzardo, sgombro, cavallo, scombro cavallo, scombro macchiato
Japan:	Honsaba, hirasaba, masaba, saba
Libia:	Kawali

Madeira Islands: Auru bea

Malta: Kavall, pizzintum

Marshall Islands: Ikaboe, molmol

Mexico: Cachorreta, macarela, macarela del Pacífico

Monaco: Cugüu

Morocco: Maquereau, kabaila

Mozambique: Sarda comum

Netherlands: Spaanse makreel

North Marianas: Mayikoro

Norway: Spansk makrell

Oman: Baljeh

Pacific Islands (Trust Territories): Smaach

Peru: Caballa verle

Philippines: Ababangon, aguma-a, alumahan, anduhau, bulao-bulao, Haguma-a, Japan mackerel, lumahan, mata-an, salay-salay

Poland: Makrela kolias

Portugal: Cavalha, cavala, cavalinha

Romania: Colios

Russia: Skumbrii, Yaponskoj skumbrii, Afrikanskaya skumbriya, Atlanticheskaya skumbriya, Kalifornijskaya skumbriya, vostochnaya skumbriya, yuzhnaya skumbriya

Serbia: Bilica, juja

Syria: Scamber

South Africa: Mackerel, Makriel

Spain: Estornino, caballa, caballa mora, barat, barat d'ull gros, bis, biso, bisol, biret, bissu, cavalla vera, gallimo, vissu, perilla, pintada, verdel, begui aundi, beguiaundi, beguihaundi, betaudxe, betautxe, cuervas

St. Helena: Mackerel

Sweden: Spansk och japansk makrill, japansk makrill, spansk makrill

Tunisia: Scournou, skoumbri, sqoumri

Turkey: Kolyoz, uskumru baligi

Ukraine: Vostochnaya skumbriya

Uruguay: Caballa

USA: Pacific mackerel, Japanese mackerel, blue mackerel, greenback mackerel, striped mackerel, chub mackerel, American mackerel

Venezuela: Cachorreta, carite, macarela

Viet Nam: Cá thu Nhât-ban

Yugoslavia: Skusa

1.3 Morphology

1.3.1 External morphology

Scomber japonicus Houttuyn, 1782 has an elongate and rounded body, pointed snout, and slim caudal peduncle. The head is small and the lower jaw slightly prominent. The mouth is wide and the teeth of the adult are thin, thinner on the vomer, conical projections situated in a single line on each of the premaxillaries and mandibles (Kramer, 1960; Dávila-Fernández, 1985). The tongue is small , with its basal part united to the glossohyal, and finishes in a cartilaginous appendix (Angelescu, 1979). The eyes are relatively big with the anterior and posterior margins covered by an adipose eyelid (Lozano-Rey, 1952; Kramer, 1969; Macpherson & Allué, 1980; Collette & Nauen, 1983; Collette, 1986). The dorsal colour of live fish is pale green (dark green to steel-blue in dead fish), crossed by steel blue faint wavy lines. The lower sides and belly are silvery yellow with numerous dusky rounded blotches that are absent in very young individuals (Lozano-Rey, 1952; Collette & Nauen, 1983; Macpherson & Allué, 1980; Collette, 1986).

The chub mackerel has 2 dorsal fins, an anal fin as well as a caudal fin. The dorsal fins are well separated, the space between them being approximately equal to the length of the base of the first fin. Their radial formula is: first dorsal, VIII-XI; second dorsal, I + 9 to 13 + 5 to 6 finlets; anal, II + 9 to 12 + 5 to 6 finlets; pelvic, I + 5; caudal, 8 to 11 + 9 + 8 + 10; pectoral, I + 17 to 21. Two small keels on each side of the caudal peduncle; central keel between them absent.

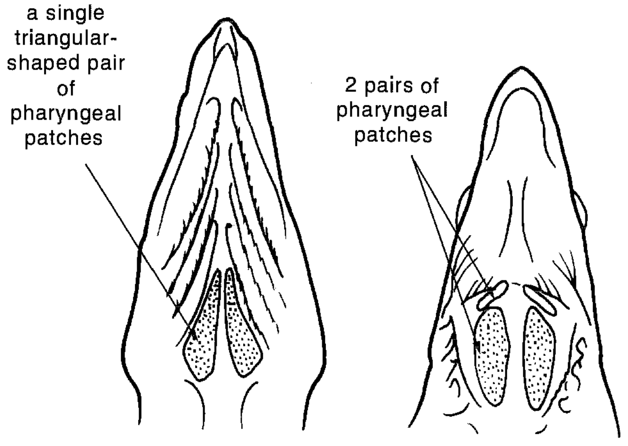
The scales are small and easily lost, although they are larger and more conspicuous around the gular region and pectoral fins than those covering the rest of the body, without presenting a well-developed corselet. It has only one, small flap (interpelvic process) between the pelvic fins (Lozano-Rey, 1952; Collette & Nauen, 1983). The maximum length from the tip of the snout to the bifurcation of the caudal fin usually reaches 50 cm, although the most common size is 30 cm (Fischer *et al.*, 1981; Collette & Nauen, 1983; Whitehead *et al.*, 1986).

Table 1 shows equations for the morphometric relationships between total length (TL) and other body measurements in juveniles (smaller than 14 to 15 cm TL), adolescents (between 14 to 15 and 27 to 28 cm TL) and adults (larger than 28 cm TL), according to Lorenzo (1992).

1.3.2 Internal morphology

The chub mackerel has 14 precaudal plus 17 caudal vertebrae, and 12 to 15 interneural bones under the first dorsal fin. The caudal vertebrae are all approximately of the same size (Lozano-Rey, 1952; Kramer, 1969; Macpherson & Allué, 1980; Collette & Nauen, 1983; Collette, 1986).

It has two pairs of sharp-tooth patches on the dorsal wall of the pharynx and a triangular shaped pair on the ventral wall (Fig. 4). A tube-shaped space runs from the mouth cavity to the posterior region of the cardiac stomach. The oesophagus is short and provided in its internal part with strong longitudinal folds. The stomach has the aspect of a conical and lengthened sack and is constituted by the cardiac region which has a posterior part or "fundus" of fine walls and great capacity of extension toward the rectal intestine, and the pyloric region which is small and of muscular thick walls (Angelescu, 1979). Kariya *et al.* (1969) reported that the stomach length decreased with time after satiation, in proportion to the stomach contents. The pylorus of the stomach is surrounded with numerous pyloric appendices. The intestine folds into an "N"- shape and measures 1/2 of the body length in larvae, growing to about a full body length in fishes larger than 10 cm, and to about 1.08 to 1.2 times the body length in adults (Yamashita, 1957; Angelescu, 1979). It does not have cutaneous artery. The liver is simple, with only one lobe. Chub mackerel have a swimbladder with a relative volume of 2.8% (Torres *et al.*, 1984) which is provided with a pneumatic duct (Lozano-Rey, 1952; Collette, 1986).



a) ventral wall **b) dorsal wall**

Figure 4. Pharynx

(after Angelescu, 1979)

The ovaries are symmetrically located. The posterior end of each ovary leads into a very short oviduct, the left and right ducts being fused into a common tube. In the spawning season the ovary is well developed, large and thick, filling up the abdominal cavity (Ciechomski & Capezzani, 1969).

The number of gill rakers in the first branchial arch varies between 13 and 19 for the minor branch and between 27 and 37 for the major branch, and tends to stabilize in preadults and adults of 21.5 to 23.5 cm (Bonnet, 1970; Angelescu, 1979; Ostapenko, 1988). The inner edges of the gill rakers are covered with numerous short, spiny protuberances. These spines are thin, about as long as the gill-raker gap, and evenly spaced to form a finer sieve between adjacent rakers. The remaining three branchial arches lack gill rakers. The width of the gill raker gap is 1.2 to 1.4 mm (Magnuson & Heitz, 1971), and the minimum size of food selected ranges from 0.03 to 0.4 mm (Hiyama & Yasuda, 1957). Cota-Meza *et al.* (1993) show that there is allometric growth between all three segments that compose the branchial arch and their gill rakers as a function of the standard length (SL). The spiny interspace increase when the length of the gill rakers increase.

Table 1. Morphometric relationships between total length (TL) and fork length (FL), length to the anal fin (AL), length to the first dorsal fin (FD), length to the second dorsal fin (SD), length to the operculum (HL), length to the pectoral fin (PL), length to the ventral fin (VL), the eye diameter (O), and the body height (H) (* adolescents and adults included)

TOTAL	JUVENILES (smaller than 15 cm TL)	ADOLESCENT (between 15 and 28 cm TL)	ADULTS (larger than 28 cm TL)
$FL = 0.970(TL^{0.985})$			
$AL = 0.576(TL^{1.013})$			
	$FD = 0.307(TL^{0.007})$	$FD = 0.348(TL^{0.964})$*	
$SD = 0.559(TL^{1.009})$			
	$HL = 0.213(TL^{1.056})$	$HL = 0.362(TL^{0.864})$*	
	$PL = 0.231(TL^{1.066})$	$PL = 0.363(TL^{0.901})$	$PL = 0.443(TL^{0.836})$
	$VL = 0.260\ (TL^{1.036})$	$VL = 0.335(TL^{0.946})$	$VL = 0.534(TL^{0.808})$
	$O = 0.051(TL^{1.091})$	$O = 0.088(TL^{0.905})$	$O = 0.185(TL^{0.668})$
	$H = 0.128(TL^{1.025})$	$H = 0.062(TL^{0.062})$	$H = 0.089(TL^{1.168})$

1.3.3 Cytomorphology

Kijima *et al.* (1986) found genetic differences between ***Scomber japonicus*** and ***S. australasicus*** at six out of 23 loci examined, i.e. αGpd-B (alpha-glycerophosphate dehydrogenase), Idh-A (isocitrate dehydrogenase), Ldh-A (lactate dehydrogenase), Sod (superoxide dismutase), Hem-1 (haemoglobin) and Hem-2 (Table 2).

- Subpopulations and/or stocks

Matsui (1967) and Collette & Nauen (1983) differentiated three populations of ***S. japonicus*** in the temperate zones of the Pacific Ocean and the western and eastern Atlantic Ocean. Fish of the Pacific population usually lack the pigmentation pattern on the belly or have this only lightly marked, the mandibular and premaxillary teeth are lightly crenulated, the scales are smaller than those of fish from the Atlantic, and the number of gill rakers on the lower first arch of individuals of 8 cm SL or greater ranges between 25 and 29, coinciding with the population of the western Atlantic. The Atlantic populations usually have the belly clearly marked by fairly large spots or by broken wavy lines that almost resemble spotting, the mandibular and premaxillary teeth are strongly crenulated, and the number of gill rakers on the lower first arch are between 29 and 35.

Table 2. Enzyme system and tissues analysed, electrophoretic buffer used, genetic loci coding to each enzyme system and their genetic differentiation. C-AEA and C-APM are citrate-aminopropyl diethanol amine buffer (pH 7.0) and citrate-aminopropyl morpholine buffer (pH 6.0), respectively. ND and D are non-divergent locus and divergent locus, respectively (* reversible frequency of allele in the locus)

ENZYME		ISOZYME TISSUE	BUFFER-SYSTEM	LOCUS	NOTE
ADH (alchol dehydrogenase)	ADH	liver	C-AEA	Adh	ND
αGPH (alpha-glycerophosphate dehydrogenase)	αGPD-A	muscle	C-APM	αGdp-A	ND
	αGPD-B	liver	C-AEA	αGdp-B	D
AAT (as partate aminostransferase)	AAT-A	liver	C-AEA	Aat-A	ND
	AAT-B	liver	C-AEA	Aat-B	ND*
GPI (glucosephosphate isomerase)	GPI-A	heart	C-AEA	Gpi-A	ND
	GPI-B	heart	C-AEA	Gpi-B	ND
IDH (isocitrate dehydrogenase)	IDH-A	muscle	C-AEA	Idh-A	D
	IDH-B	liver	C-AEA	Idh-D	ND
LDH (lactate dehydrogenase)	LDH-A	eye	C-AEA	Ldh-A	D
	LDH-B	eye	C-AEA	Ldh-B	ND
	LDH-E	eye	C-AEA	Ldh-E	ND
MDH (malate dehydrogenase)	MDH-A	muscle	C-AMP	Mdh-A	ND
	MDH-B	heart	C-AEA	Mdh-B	ND
	mMDH	muscle	C-AMP	mMdh	ND
ME (malic enzyme)	ME-A	muscle	C-AEA	Me-A	ND
	ME-B	muscle	C-AEA	?	?
PGM (phosphoglucomutase)	PGM	liver	C-AEA	Pgm	ND*
SDH (sorbitol dehydrogenase)	SDH	liver	C-AEA	Sdh	ND
SOD (superoxide dismutase)	SOD	liver	C-AEA	Sod	D
SP (sarcoplasmatic protein)	SP-1	muscle	C-AM-	Sp-1	ND
	SP-2	muscle	C-AMP	?	?
	SP-3	muscle	C-AMP	?	?/
	SP-4	muscle	C-AMP	Sp-4	ND
HEM (haemoglobin)	HEM-1	heart	C-AEA	Hem-1	D
	HEM-2	heart	C-AEA	Hem-2	D

Viskrebenzev (1963) analysed the degree of commonness of antigens of chub mackerel from Senegal, Gulf of Guinea and Cape Frio (Namibia), and concluded that their heterogeneity seems to indicate a definite genetic inadequacy. In his opinion, this was an evidence of differences between the three forms probably on a subspecies or even lower level. Weiss (1980) performed electrophoretic serum analyses, using immune serum with rabbit blood, test on substances active in blood groups, and hetero-agglutination with rabbit and human blood. He found similar reactions in samples caught along the coast of northwest Africa from 12 to 21°N, differing reactions for samples from 29 and 25°N, and both types of reactions in the 22°N region. Weiss (1980) demonstrated the homogeneity of the stock between 21 and 12°N. This is in agreement with findings of Barkova & Krivospitchenko (1990), who considered that there is only one stock that inhabits the waters of Western Sahara and Mauritania.

There are two hypotheses concerning population structure of the southeast Atlantic chub mackerel. The first is that there is a single chub mackerel population in the southeast Atlantic area, the distribution range of which shifted from the southern to the northern part of the Benguela Current in the last decade (Batalyants, 1986). Data from oceanographic research on the southwest African shelf (Shannon, 1986a), together with information on spawning grounds and growth rates of some commercially important fish species, are suggestive of discrete populations in the area. This allows to suppose the existence of different populations south and north of the Benguela current, with an ecological barrier in the zone of Cape Lüderitz (Shannon, 1986b; Shannon & Agenbag, 1987; Ostapenko, 1988). Zenkin & Lobov (1988) reported that the genetic-biochemical studies of sarcoplasmatic proteins revealed biochemical polymorphism. The results of the morphological studies revealed two polymorphic traits, one associated with the skin pattern on the dorsal part of the body and the other with the skin pattern on the lateral line. Population genetics analysis of chub mackerel samples from ICSEAF Divisions 1.3, 1.4 and 1.5, by gene frequency and the level of heterozygosity for polymorphic protein loci, as well as by phenotype and gene frequency in two loci of the external features, showed that the Namibian chub mackerel is genetically homogeneous and has a similar gene pool in all Divisions. All the data collected by Zenkin & Lobov (1988) indicate that chub mackerel in ICSEAF Divisions 1.3 to 1.5 form a single population.

Matsuura & Sato (1981) concluded that there are probably two separate spawning stocks off Brazil, one in the Cabo Frio region (Río de Janeiro) and one in the Santa Catarina Island region. Angelescu & Gneri (1964) reported that there is a great homogeneity in the meristic characters of chub mackerel caught off Mar del Plata area (Argentina). Ciechomski & Capezzani (1969), based on data from Angelescu & Gneri (1964) and considering the existence of a short spawning period, suggested that there is only one population of chub mackerel in the area off the Buenos Aires Province. However, Perrotta & Aubone (1991) verified that fish from Mar del Plata and from the marine front of Río de La Plata form a single group, and suggested a separate group for fish from the El Rincón. López (1959) suggested the presence of the subspecies ***Scomber japonicus marplatensis***, which is conformed by a single population extending from the south of Brazil to the north Patagonia area in Argentina. This was put in doubt by Perrotta *et al.* (1990a), basing their opinion on the lack by López of a greater number of samples from different areas, and the fact that he only had two fish from Río de Janeiro (Brazil). Furthermore, Perrotta *et al.* (1990a) demonstrated that chub mackerel from the south of Brazil and from the area of Mar del Plata constitute segregate populations. The differences are associated with the size of the head, the number of rays of the pectoral fin and the number of gill rakers.

Racial differences in the chub mackerel of the northeast Pacific were investigated by Fry & Roedel (1949) and by Roedel (1952a). Roedel (1952a) examined specimens from six geographic regions: British Columbia, southern California, northern Baja California (Soledad Bay), central Baja California (Vizcaino Bay), the Cape San Lucas region including sections of the Pacific and gulf coasts of the peninsula, and the Gulf of California. Four physical characteristics were selected for detailed study. Statistical analyses gave evidences of five populations, each region with the exception of British Columbia and California, being separable in some degree from adjoining regions. However, tag returns (Fry & Roedel, 1949) demonstrated that a portion of Vizcaino Bay fish eventually reached California waters. The Cape San Lucas fish were totally different to fish from the northern regions and were separable from fish of the Gulf of California except in regard to the initial position of the haemal arch. Gluyas-Millán & Quiñones-Velázquez (1996) identified two stocks, one distributed from southern California to Vizcaino Bay and the other in the Gulf of California. Both stocks overlapped at Magdalena Bay, which seems to be a feeding ground for young individuals that have not been recruited to the spawning stock.

Rohde (1987) using monogenean sclerites, concluded that there are different populations of ***Scomber japonicus*** in Japan and Ecuador. Stepien & Rosenblatt (1996) reported that the tropics appear to have been a formidable barrier to movement between northern and southern populations of chub mackerel in the north and southeast Pacific. Serra (1983), based on information obtained from studies in spawning areas, suggested the existence of two populations in the southeast Pacific, one in the central north of Peru and another in the north of Chile. Additionally, Dawson (1986) based on growth parameters, pointed out that chub mackerel occurring off the coast of Ecuador, Peru and Chile consist of two stocks. One stock is thought to inhabit the area off Ecuador and northern Peru, and the other stock occupies the waters off southern Peru and Chile, with some mixing of the two stocks occurring in the central area (Anon, 1984).

Several populations of chub mackerel live in the Sea of Japan, East China Sea, and off the eastern coast of Japan (Usami, 1968; Sato, 1968; Watanabe, 1970; Kawasaki, 1971b; Novikov, 1977; Tanaka, 1983; Belyaev & Ryabov, 1987; Ivanov, 1989). All reports consider chub mackerel from the Sea of Japan, East China Sea, and Pacific Ocean to consist of separate populations. The main evidence for this is the complete isolation of spawning areas in these populations, a clear separation of their feeding areas, and the periods of maturation and spawning. Usami (1973) assumed that the chub mackerel population around Japan consisted of three major subpopulations. The Pacific subpopulation, occupying the waters off the northeast Pacific coast of Honshu (Kuroshio Current area), the Sea of Japan subpopulation (Tsushima Warm Current area), and the East China Sea subpopulation. Two stocks, off Tottori and off west Kyushu, form the East China Sea subpopulation (Iizuka & Hamasaki, 1986). The studies on biochemical polymorphism testify the heterogeneity of the chub mackerel populations from the Pacific waters of Japan (Ryabov & Belyaev, 1983). Belyaev & Ryabov (1987) observed that their samples could be divided into three very distinct phenotypic groups or subpopulations. Chub mackerel of group I were found in open waters during September-October, while in December they were found off the Boso Peninsula. Groups I and II have greater similarity to each other, while group III was found only in the open sea and does not arrive at the shelf until sexual maturation. This last group distributes southerly of the first two groups. According to the qualitative and quantitative composition of the helminth fauna, Pozdnyakov & Vasilenko (1994) found that there are two relatively isolated reproductive groups of chub mackerel in the northwestern Pacific.

1.3.4 Protein specificity

Kijima *et al* (1986) detected 11 enzymes and two non-enzymatic proteins in muscle, liver, heart and eye of chub mackerel (Table 2).

2. DISTRIBUTION

2.1 Total area

Scomber japonicus is a cosmopolitan coastal-pelagic species from temperate waters. It is found over the continental slope from the surface to a depth of 300 m, and reaches its deepest levels during the day (Lozano-Rey, 1952; Collette & Nauen, 1983). This species inhabits warm and temperate waters of the Atlantic, Indian and Pacific oceans and adjacent seas (Collette & Nauen, 1983) (Fig. 5).

In the eastern Atlantic it is frequent along the African coast, being present from Morocco to South Africa, including the Azores, Madeira, Canary and Saint Helena Islands (Lozano-Rey, 1952; Razniewski, 1967; Habashi & Wojciechowski, 1973; Wray, 1979; Baird, 1978a; Edwards & Glass, 1987; Castro, 1993) and on the Great Meteor sea mount (30°N to 28°30'W; F. Uiblein, Univ. Salzburg, Austria; pers. comm.). Toward the north, it is found up to the Gulf of Biscay and, occasionally the south of the

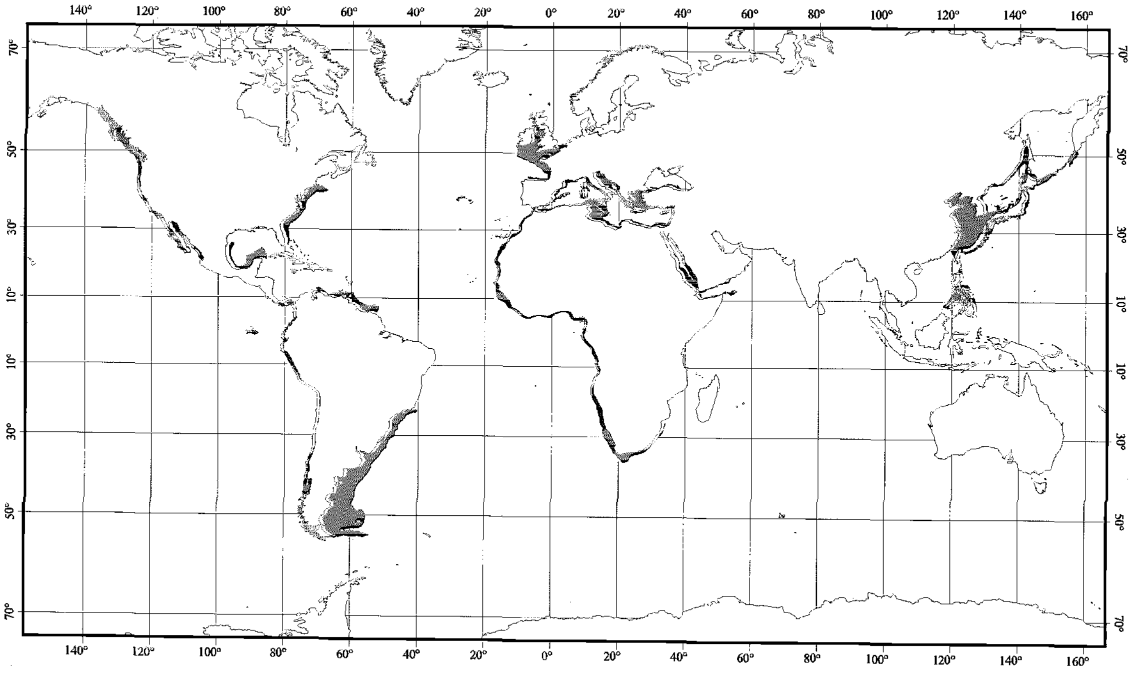


Figure 5. Total distribution area of *Scomber japonicus*

British Isles, the Irish Sea and the coast of Belgium (Collette, 1986; Quigley & Flannery, 1994). It is also present in the Mediterranean Sea and in the southern Black Sea (Slastenenko, 1955; Rodríguez-Roda, 1982; Ben-Tuvia, 1957; 1983; Collette, 1986). In the Atlantic coast of America this species is frequent from Massachusetts to Florida (USA), the Bahamas, the Gulf of Mexico and southern Venezuela (Fry, 1936b; Matsui, 1967). It is also important off Brazil, Uruguay and Argentina (Angelescu, 1979, 1980; Sánchez, 1982; Seckendorff & Zavala-Camin, 1985; Goberna, 1987).

In the northeast Pacific Ocean this species is distributed from the southeast of Alaska to Banderas Bay (Mexico) and in the Gulf of California to Puerto Peñasco; in the southeast Pacific it extends from Panama to Darwin Bay (Chile) including the Galapagos Islands (Fry, 1936b; Mann, 1954; Fitch, 1953; Matsui, 1967; Kramer, 1960; Kramer, 1969, Parrish & MacCall, 1978; Pequeño, 1979; Martínez & Bore, 1980; Schaefer, 1980; Konchina, 1982; Mora-Lara, 1983; Pizarro de Rodríguez, 1983; Mendo, 1984; Díaz-Ocampo, 1991; Hildebrand, 1946). In the West Pacific it is present from the Kurile Islands, in the north, to the East China Sea and Taiwan Province of China, and toward the south to the Philippines (Belyaev & Ryabov, 1987; Hatanaka *et al.*, 1957; Nishimura, 1959; Takano, 1954; Usami, 1973; Watanabe, 1970).

In the Indian Ocean it has been reported around the coast of the Arabian Peninsula, and is said to be very important in the Red Sea (Ben-Tuvia, 1957; Kukharev *et al.*, 1993). However, Baker & Collette (1998) identified the population of ***Scomber*** from the Red Sea and northern Indian Ocean (Gulf of Aden and Oman) as ***S. autralasicus*** rather than ***S. japonicus***. It is also present at the coast of Somalia (Sanders & Morgan, 1989).

2.2 Determinant of distribution changes

See point 5.5. Climatic influences

2.3 Hybridization

Hybrids have not been observed (Kijima *et al.*, 1986).

3. BIONOMIC AND LIFE HISTORY

3.1 Reproduction

3.1.1 Sexuality

Scomber japonicus is heterosexual, without evidence of sexual dimorphism (Kramer, 1969).

3.1.2 Maturity

Tuggaç (1957) reported that in the Marmara Sea (Turkey) chub mackerel spawn during their second summer, while Atli (1960) reported that spawning takes place during the third year of life in Dardanelos and the Black Sea. Rodríguez-Roda (1982) found that this species does not spawn until it reaches 30 cm of fork length (FL) off the Gulf of Cádiz (Spain). Martins *et al.* (1983) reported that 50% of the fish reach maturity at 31 cm or during age group III off Portugal.

Along the northwest African coast, the length of first maturity was estimated at 31 cm TL by scientist of the ex-GDR (German Democratic Republic) (FAO, 1986). Razniewski (1967) found many mature specimens of 16 to 22 cm TL (1-year-old), while most of individuals between 20 and 30 cm (2-year-old) were mature. Alekseev (1969) reported that the chub mackerel reaches sexual maturity at age 3 years and a length of 27 to 31 cm. He also reported that some males mature in the second year and some females in the fourth year of life. Russian researchers estimated the length of maturity at 25.7 cm in the Western Sahara zone, and at 22.2 cm, corresponding to 1.8 years old, in Senegal; along the Senegal-Mauritania zone, Rumanian experts estimated the size of first maturity to be 24.36 cm, corresponding to 2.2 years old (FAO, 1986). This is in agreement with Weiss (1981) who observed that chub mackerel between Cape Verde and Cape Blanc, were fully developed in the second year and showed a characteristic reproductive behaviour. In the Canary Islands, the mean sizes of first maturity are 19.85 cm and 19.90 cm TL for males and females, respectively, and all adults are mature at 26 cm TL (Lorenzo, 1992; Lorenzo & Pajuelo, 1993). Off South Africa, Baird (1975; 1977) observed that all fish smaller than 33 cm of SL were immature (2 years old), while fish larger than 42 cm were mature, when they are in their third or fourth year of life.

In waters off southern Brazil, Seckendorff & Zavala-Camin (1985), found that maturity begins at 18 cm FL. Off Argentina, Angelescu (1979) reported that the size of first maturity fluctuates between 18.5 and 23.5 cm TL.

In the eastern Central Pacific, Fitch (1952) observed that most chub mackerel do not spawn until their third or fourth year of age, however, Fry (1936b) states that yearling chub mackerel fish do not spawn, whereas most of the 2-year-olds do. Knaggs & Parrish (1973) observed that no fish spawn during their first season (age group 0), and only 22.5% of 1- year-old fish were mature. Parrish & MacCall (1978) analysed the original samples used by Knaggs & Parrish (1973) to determine if the percent of maturity of age-1 fish is density dependent. They found that 50.3% of the age-1 fish were mature or maturing during 1969-1971, when the spawning biomass was low.

In Baja California (Mexico), Arcos-Huitron & Torres-Villegas (1990) found that the range of minimum maturity size ranged between 21.8 and 22.3 cm. However, off Vizcaino Bay (Pacific coast of Mexico), Gluyas-Millán (1994) reported that length and age at first maturity were 29.3 cm SL and 4.3 years, respectively. Gluyas-Millán (1989) observed that spawning can occur at different times in Vizcaino Bay, Magdalena Bay and the Gulf of California, and that mean SL, total weight and recruitment size tend to decrease from Vizcaino Bay to the Gulf of California.

Chub mackerel off Peru are reported to reach first sexual maturity at 27 cm of length (Schaefer, 1980). Jordán *et al.* (1978) report a high incidence of chub mackerel in spawning condition at 31 cm. Kotlya & Abramov (1983) observed that 60 to 80% of the fish attain sexual maturity in the first year (beginning at a length of 18 to 19 cm), and up to 90% are mature in the second year of life. On the other hand, Alekseev & Isakov (1986) estimated that the length of first maturity was 22 cm. Miñano & Castillo (1971) and Mendo (1984) reported that first maturity is reached at 26 to 28 cm, almost coinciding with the size of massive maturity of 27 to 28 cm suggested by Alekseev & Isakov (1986), while Miñano & Castillo (1971) and Mendo (1984) observed that 50% of the population spawn at a size between 31.5 and 34.5 cm. Martínez & Boré (1980) reported that the maturity size was over 32.5 cm TL. Off northern Chile, Serra (1983) reported that the size of first maturity was 30 cm FL. However, Pardo & Oliva (1992) observed that according to the macroscopic and microscopic criteria, the size at first sexual maturity was 25.9 cm and 26.2 cm FL, respectively, while the average spawning size was 27.3 cm and 28.4 cm respectively.

Itoh (1954) reported that a chub mackerel sampled in the Sea of Japan, which was 27.5 cm, had a ripe ovary. Enami (1958) described that off the Tsushima Current, these fish mature at about 25.5 cm. Usami (1968; 1973) estimated that the minimum size for spawning in waters off the northeastern Pacific coast of Honshu (Japan), is 30 cm in FL, when fish are 2 years old. Watanabe (1970) determined that the minimum female size at the first maturity for females is 29 cm in length.

3.1.3 Mating

No information available to the authors.

3.1.4 Fertilization

Fertilization is external in the chub mackerel (Kramer, 1969).

3.1.5 Gonads

Coefficient of fecundity

Off the Atlantic coast of Portugal Martins & Serrano-Gordo (1984) found that the gonadosomatic index was 9.7 in males and 7.5 in females. Off Peru, Mendo (1984) found that the maximum value of the gonadosomatic index was 8.0 during January. In the Japan Sea, Asano & Tanaka (1989) reported that the mean gonadosomatic index ranges widely from 4.0 to 5.0 up to 20.0 or more. Watanabe (1970), Usami (1973) and Asano & Tanaka (1989) reported that mature chub mackerel spawn when the maturity coefficient was greater than 5.

Knaggs & Parrish (1973) pointed out that males mature earlier in life than females. The maturity coefficient in females is generally larger than in males during the immature stage, but this situation reverses with growth. The peak of maturity is reached earlier in males than in females (Watanabe, 1970; Usami, 1973; Asano & Tanaka; 1989). Perrotta & Christiansen (1993) corroborate that off Argentina, the gonadosomatic index changes synchronically in both sexes and that it is higher in males than in females, inverting the relationship at the beginning and end of the fishing season.

The relative oocytic surface in fish that have spawned recently is between 0.13 and 0.21 (0.19 in average). The relative oocytic surface in ovaries just before spawning ranges between 0.33 and 0.41 (Perrotta & Christiansen, 1993).

3.1.5.1 Description of maturity stages

The following description of the maturity stages is based on studies from the northeast, southeast and southwest Atlantic, and from the northwest and southeast Pacific Oceans (Ciechomski & Capezzani, 1969; Watanabe, 1970; Baird, 1977; Arriaga *et al.*, 1983; Martins & Serrano-Gordo, 1984; Mendo, 1984; Seckendorff & Zavala-Camin, 1985; Asano & Tanaka, 1989).

- Stage I (immature, virgin)

Anatomical characteristics: Testis and ovaries thin (over 2 to 3 mm in diameter) and thread-like, adhered to the swimbladder, translucent and nearly colourless, oocytes and blood vessels not visible to the naked eye, sexes usually indistinguishable. The mean gonadosomatic index is less than 1.0. The maximum diameter of the oves varies from 0.05 to 0.2 mm. This type of ovaries appear during the feeding and wintering periods.

Histological characteristics: The ovary has abundant connective tissue and well-formed proliferating crests. There are oogonia and previtellogenetic polyhedral oocytes dominating the visual field of the oogonia. The rounded oogonia have a large nucleus with one or two nucleoli of large size, and a fine layer of cytoplasm that becomes weakly tinted with the hematoxyline. The polyhedral oocytes are of larger size than the oogonia, they have a large nucleus and nucleoli grouped in the periphery, and a large amount of strongly basophilic cytoplasm.

- Stage II (maturing virgins or recovering spent)

Anatomical characteristics: Gonads developing and filling half of the body cavity. Ovaries more rounded (over 3 to 8 mm in diameter), and beginning to enlarge, colour translucent pinkish, eggs and blood vessels not visible to the naked eye. Testis thin and strap-like, beginning to thicken and of a slight white coloration. The mean gonadosomatic index ranges from 1.0 to 4.0. The most advanced egg group has a peak size ranging from 0.2 to 0.4 mm.

Histological characteristics: Proliferating crests well formed, converging towards the centre of the lumen. Two prevailing types of oocytes: without yolk (previtellogenetic oocytes) and acquiring yolk. The non-yolked oocytes have borders with attenuated angles, show a progressive decrease of the polyhedral form, have numerous outer nucleoli in the nucleus, and present a larger nucleolus than the other oocytes. Those oocytes starting vitellogenesis become rounded as they grow. The yolk appears in the form of vesicles in the periphery of the cytoplasm, becoming granular and less basophilic. In general, the cytoplasm begins to lose affinity for hematoxyline in these two types of oocytes. The polyhedral oocytes and the oogonia are present. In the case of a recovering ovary, it is possible to find postovulatory follicles of less than 48 hours and atretic cells.

- Stage III (Maturing)

Anatomical characteristics: Gonads maturing and filling approximately two-thirds of the body cavity. Ovaries yellow or pale orange, with abundant blood irrigation. The ova are small and opaque, visible to the naked eye, with a diameter ranging between 0.3 and 0.8 mm. Testis opaque white and smooth. The gonadosomatic index varies between 1.5 and 7.0, with an upper limit of 10.5.

Histological characteristics: Proliferating crests very marked, larger that in the previous phase due to the growth of the oocytes, in some cases occupying the whole lumen of the ovary.

Most oocytes have a cytoplasm with abundant eosinophil yolk granules and lipid vesicles, which could occupy the whole cytoplasm. These oocytes have well-defined follicular layers. The outer nucleoli are still present, but are extremely reduced in size. There are previtellogenetic oocytes squeezed-in by oocytes beginning the vitellogenesis.

- Stage IV (Ripe)

Anatomical characteristics: Gonads at maximum size and filling the body cavity. Ovaries dark yellow or orange; pressing the belly causes the extrusion of translucent pale-golden eggs. Testis opaque white, crumbly in texture, milt extruded by pressure on abdominal wall. Roe and milt running (spawning). The most advanced eggs range in diameter between 0.9 and 1.29. The mean gonadosomatic index ranges widely from 4.0 to 5.0 up to 20.0 or more.

Histological characteristics: Ovaries with lumen not distinguishable due to the distension of the proliferating crests. Most oocytes in advanced state of vitellogenesis or hydrated. The oocytes in advanced state of vitellogenesis have the cytoplasm full of eosinophil yolk granules, and in some cases the nucleus is little distinguishable. Upon hydration the oocytes, lose their rounded form due to their growth when entering in contact with each other.

The hydrated oocytes are characterized by having a weakly basophilic and uniform cytoplasm lacking yolk granules. The lipoid vesicles converge, constituting the oleaginous globule. The oocytes have an eccentric nucleus that will constitute the animal pole. The follicular layers are well conformed. It is also possible to locate postovulatory follicles of age zero, alpha, and beta stage atretic oocytes, previtellogenetic oocytes, and oocytes in the initial stages of vitellogenesis.

- Stage VII (Spent)

Anatomical characteristics: Ovaries slack, thin, bloodshot, and translucent. It is possible to observe a few remaining hydrated oocytes. Testis thin, flaccid, bloodshot. The gonadosomatic index varies between 2.1 and 7.8.

Histological characteristics: Ovaries showing evidence of a recent spawn are characterized by a great disorder of the structures. Proliferating crests not very well defined, due mainly to the presence of numerous postovulatory follicles, which are a consequence of the recent spawn. The ovary presents scarce remnants of hydrated oocytes, atretic oocytes (alpha and beta), immature previtellogenetic oocytes and in beginning of vitellogenesis.

3.1.5.2 Fecundity and egg size

Eggs of an individual fish in successive batches (Tuggaç, 1957; Ciechomski & Capezzani, 1969; Knaggs & Parrish, 1973; Retamales & Gonzales, 1981; Arriaga et al., 1983; Peña et al., 1986; Asano & Tanaka, 1989; Oliva, 1989; Perrotta & Christiansen, 1993; Murayama et al., 1995). Ripe translucent eggs appear irregularly in the ovary among still unripe ova in early stages of development (Knaggs & Parrish, 1973). Perrotta & Christiansen (1993) estimated that successive spawnings occurred about every 18 to 20 days and a maximum of about every 25 days. Yamada et al. (1996) found that among 273 females, 19 females spawned almost every day. Lushkareva (1960) considered that chub mackerel spawn three times during a single reproductive season, however, Perrotta & Christiansen (1993) found 4 or 5 ova generations within the same gonad. During the first spawning, the female sheds about 50% of the total number of yolked eggs within her ovaries (Lushkareva, 1960).

In the Sea of Japan, a single female chub mackerel of 32 cm SL produces 441 795 eggs, and a female of 46 cm produces 1 859 173 eggs (Lushkareva, 1960). In her calculation, Lushkareva counted all yolked ovarian eggs. Song et al. (1988), working off the northern Yellow Sea during June 1984 and May 1985 found that individual absolute fecundity increases exponentially with net weight, fork length, and age, ranging from 195 400 to 900 400 eggs, and averaging 531 600 eggs. Off Argentina, Ciechomski & Capezzani (1969) reported that the fecundity of the smallest female of 31.5 cm TL was estimated to be 101 859 eggs, and the total number of yolked ova was 181 000; this was 522 370 and 853 500 eggs, respectively, for the biggest female of 47 cm in length. Off Chile, Díaz-Ocampo (1991) observed that the mean number of eggs produced per female was 150 019 ± 63 403.

Off northeast Honshu (Japan), Usami (1973) found that the large ova of ready-to-spawn chub mackerel are mostly 0.5 to 0.7 mm in diameter, and that few eggs attain 0.7 to 0.8 mm. Accordingly, the time taken by eggs 0.5 to 0.7 mm to grow to about 1.0 mm, seems to be very short. Ciechomski & Capezzani (1969) reported that the largest eggs they found in the ovary of a fish of 41.4 cm long and 715 g total weight were about 1.29 mm in diameter. Asano & Tanaka (1989) found that egg diameter in the ovaries varied between 0.15 and 0.2 to about 1.0 mm. A batch of eggs moves rapidly from the immature stage (less than 0.3 mm) to the developing stage (about 0.6 mm), accumulating yolk in each egg and stopping there. Then the egg-batch prepares for spawning by increasing the number of eggs. Spawning occurs after the preparation is completed. Eggs hydrate at about 0.9 mm in diameter and are shed when they reach a diameter of 1.0 to 1.2 mm (Asano & Tanaka, 1989). Kramer (1969) reports that egg size oscillates between 1.06 and 1.14 mm.

Good descriptions of egg morphology and development of ***Scomber japonicus*** can be found in Fry (1936a), Kramer (1960), Watanabe (1970), and Kuroda *et al.* (1982).

3.1.6 Spawning

3.1.6.1 Spawning season and location

The spawning season varies between regions (Table 3), although it seems to be usually limited to the first half of the year in the northern hemisphere, while in the southern hemisphere it occurs in the second half of the year. In areas close to the equator such as Peru, the spawning takes place all year round.

In the Sea of Marmara, Demir (1961) found that spawning areas cover neritic waters where depths vary between 15 and 250 m. However, the largest number of eggs and larvae per haul were caught in areas with depths of 40 to 100 m. Weiss (1981) reported that the main spawning grounds off Senegal-Mauritania were located south of Cape Vert and north of Cape Blanc. However, Garcia (1986) found that the spawning area of chub mackerel in northwest Africa was between Cape Juby and Cape Blanc, whereas the nursery areas were south of Cape Blanc and Cape Vert. Habashi & Wojciechowski (1973) reported that spawning takes place in shallow waters, and that in the Western Sahara and Moroccan coasts, spawning takes place later than in Mauritania and Senegal.

Off South Africa, chub mackerel spawn off Columbine in winter and early spring (Baird, 1975; 1977) when inshore currents spurred by northwesterly winds bring relatively warm water (14 to 15°C) nearer to the coast (Shannon, 1976; Crawford, 1983). Baird (1975) reported that the largest concentrations of eggs were found between Lambert's Bay and Dassen Island in waters with temperatures of 11.5 to 6.9°C and salinity of 34.70 to 35.59‰. During the winter of 1973 and 1974, eggs were distributed over a large area, but the highest concentrations occurred west of Saldanha Bay in a patch approximately 10 nautical miles wide. It was also found that chub mackerel spawns at least twice a year. Baird (1977) defined the spawning season of this species as June-September.

In the northwestern Atlantic, Berrien (1978) showed that chub mackerel spawn in offshore waters south of Cape Hatteras during winter and spring. Surface temperatures associated with egg occurrences in the northwest Atlantic ranged from 20.4 to 25.4°C (Berrien, 1978).

Off Brazil, larvae were located in three areas during the cold season (20.4 to 24.2°C): Cabo Frio, Ilha Grande and Cabo de Santa Marta Grande (Matsuura & Sato, 1981). The spawning area of Mar del Plata (Argentina) is located at approximately 38°S (Perrotta, 1992). Ciechomski (1971) reported that the area of the spawning grounds during late November and early December 1968 was calculated as at least 155 302 km^2. In this region, spawning generally starts at a water temperature above 14.5°C, while the highest concentrations of eggs were found in waters between the isotherms of 17 and 19°C (Ciechomski, 1971). The latter author reported a density of 250 eggs/m^2 in November, with the highest concentrations found near shore (345 to 360 eggs/m^2). Angelescu & Cousseau (1982) suggested that during 1975-1976 there was a displacement of the spawning area to an unknown region, basing their hypothesis on the dominance of individuals in prespawning stages and the absence of eggs in the ichthyoplankton.

In the northeast Pacific, Parrish & MacCall (1978) indicated that the spawning stock of chub mackerel extends from British Columbia to Punta Abreojos (Mexico). In the eastern Central Pacific, Kramer (1960) stated that the main spawning areas are in Vizcaino Bay and south of Punta Eugenia to Cabo San Lucas (Baja California, Mexico). The distribution of chub mackerel larvae off southern California and Baja California was reported from 1936 through to 1941 by Fry (1936b) and Roedel (1949; quoted by Schaefer, 1980). Ahlstrom (1953; 1954; 1958; all quoted by Schaefer, 1980) and Ahlstrom & Kramer (1955; 1956; 1957; all quoted by Schaefer, 1980) have given data on the distribution of these larvae for

Table 3. Spawning seasons of *Scomber japonicus* by marine areas

AREA	MONTHS	
MEDITERRANIAN		
Adriatic Sea	April-August	Mužinic, 1979
Marmara Sea	April-July	Tuggaç, 1957
Black Sea	June-August	Atli, 1960
Israel	April-June	Ben-Tuvia, 1957
Libya	April-June	Giama, 1994
NORTHEAST ATLANTIC		
Portugal	April-June	Martins *et al*, 1983
	February-April	Martins & Serrano-Gordo, 1984
Azores Islands	April-June	Westhaus-Ekau & Ekau, 1982
Northwest Africa	December-March	FAO, 1986
		Razniewski, 1967
		Habashi & Wojciechowski, 1973
		Staicu & Maxim, 1974
Canary Islands	January-March	Delgado de Molina *et al*, 1983
	December-March	Lorenzo, 1992
Western Sahara	March-May	FAO, 1986
Mauritania	March-June	Garcia, 1986
Mauritania-Senegal	December-February	Domanevsky, 1970
	December-March	Weiss, 1981
	January-March	FAO, 1986
NORTHWEST ATLANTIC	Winter-Spring	
NORTHEAST ATLANTIC		
South Africa	June-September	Baird, 1975; 1977
		Crawford, 1981
SOUTHWEST ATLANTIC		
Brazil	September-January	Matsuura & Sato, 1981
	July-December	Seckendorff & Zavala-Camin, 1985
Argentina	December-February	Gagliardi & Cousseau, 1970
	November-December	Ciechomski & Capezzani, 1969
		Ciechomski, 1971
	October-January	Perrotta & Christiansen, 1993
NORTHEAST PACIFIC		
California	April-August	Fry, 1936b
		Kramer, 1960
	March-October	Knaggs & Parrish, 1973
Mexico	April-October	Ahlstrom, 1959
	May	Parrish & MacCall, 1978
	January-May	Arcos & Torres-Villegas, 1990
	November-April	Gree-Ruiz & Aguirre-Medina, 1992
	April-August	Gluyas-Millan, 1994
	December-April	Esqueda-Escarcega, 1995
NORTHWEST PACIFIC		
Russia	July	Vedenskiy, 1954
	June-July	Lindberg, 1949
	April-July	Belyaev & Ryabov, 1987
	December-February	Diaz-Ocampo, 1991

Table 3. (continued)

AREA	MONTHS	
Japan	May	Kishinouye, 1923
	June-July	Sano *et al.*, 1956
	April-August	Odate, 1961
	February-July	Watanabe, 1970
	March-June	Usami, 1973
		Asano & Tanaka, 1989
		Murayama *et al.*, 1995
SOUTHEAST PACIFIC		
Ecuador	November-May	French & Menz, 1983
Peru	January-March/September	Miñano & Castillo, 1971
		Santander & Castillo, 1972
	January-May/September	Jordan-Sotelo, 1979
	All year round	Kotlya & Abramov, 1983
	December-July	Mendo, 1984
	All year round	Alekseev & Isakov, 1986
Chile	January-March	Retamales & Gonzales, 1981
	January-May	Serra, 1983
	December-January	Oliva, 1989

1951 through to 1956. Ahlstrom (1959) suggests that this species spawn closer to the surface and to the shoreline in the California current region. Kramer (1960) reports that the offshore range of the larvae is about 150 miles off southern California, 250 miles off northern Baja California, and 200 miles off central Baja California. Ahlstrom (1959) and Kramer (1960) reported that no larvae were found deeper than 66 m, and nearly 80 to 94% occurred at the 0 to 23 m level. Larvae are abundant in the Gulf of California in the area between Bahía Kino and Mazatlán, and the largest concentrations are found in the southwestern portion of the Gulf of California near Santa Carmen Island, Baja California (Moser *et al.*, 1974).

In waters off Ecuador, García (1983) found that major concentrations of eggs (10 000 eggs in 110 m^2) and larvae were encountered principally in the north and south of the equator during summer (January-April). Lower values were recorded in winter months (May-December). García (1983) found that in August, eggs were limited to the south and distinguished the zone adjacent to Point Santa Elena as one of intense spawning. Off Peru, chub mackerel spawn from Cabo Blanco to San Juan (04°0.1'S to 15°30'S), over 100 miles from the coastline and limited by the penetration front of the oceanic waters (Tsukayama, 1983). This is in accordance with the observations of Alekseev & Isakov (1986) who reported that the main spawning ground is confined to the Nazca Ridge. A relatively large sample of eggs and one larva were collected at 18°32'S and 71° 42'W, and a smaller group of eggs and five larvae were collected at 20°10.8'S and 71°3 3.2'W (Ahlstrom, 1979; quoted by Schaefer, 1980). Kotlyar & Abramov (1983) recorded spawning during winter, spring, early summer, and beginning of autumn right up to the coastline. Particularly intensive spawning took place in June-November and March, although none was observed in May. Off the north of Chile spawning has been studied by Retamales & Gonzales (1981), Oliva (1989) and Díaz-Ocampo (1991) who found that spawning takes place during the summer (November-March). Serra (1983) reported that in Chile, chub mackerel spawns mainly in the north, between the Peruvian border and Antofagasta (24°S). Rojas & Mujica (1981) found larvae of chub mackerel as far out as 200 miles offshore. Surveys in the area of Talcahuano (37°S) suggested the existence of secondary spawning in that area in the months of September-October (Serra, 1983).

Belyaev & Rygalov (1986) observed that chub mackerel spawning grounds in the shelf of Honshu Island are fairly constant. However, this is related to a great extent with the existing system of currents. Watanabe (1970) and Tomosada (1985; 1989) reported that the major spawning grounds are generally on the shelf zone, near offshore islands or around submarine banks. Spawning occurs around the Kii Peninsula in February, around the Boso Peninsula and Izu-Shoto islands in March, in the Sea of Kashimanada in April, and off the Sanriku coast in May and June. Spawning begins earlier and lasts longer in the south than in the north. Uda (1970, quoted by Schaefer, 1980), Usami (1973) and Tomosada (1989) report that since 1965 the main spawning grounds have been around the Izu Island area, especially near Zenizu Reef, when water temperature is at least 10°C and most often when it is 15 to 20°C (Collette & Nauen, 1983). They also report that the main fishing season coincides with the spawning season. Kuroda (1986) reported that near the Kuroshio Front south of Cape Shionomisaki in southern Japan, the main spawning area of chub mackerel was about 30 miles wide from the Kuroshio water zone to the Kuroshio-branch warm-water zone. Watanabe (1970) reported that ovulating females (maximum diameter of ovarian eggs, 0.9 to 1.1 mm) swim in different strata from fish with mature ovaries (maximum diameter of ovarian egg, 0.6 to 0.7 mm). Ovulating females were found in depths between 50 and 100 m, at around 200 m, or near submarine banks and reefs. Spawning takes place between 2000 and 2400 hours, based on field sampling of eggs immediately after ovulation, and probably takes place in the stratum between a depth of 50 and 100 m (Watanabe, 1970). The eggs and larvae are distributed over a large water surface in the main spawning areas, and are carried passively north and northeast depending on the direction of the main force of the Kuroshio current (Belyaev, 1980b; Tomosada, 1985; Belyaev & Rygalov, 1986). Kosaka & Hirai (1988) observed that larvae of chub mackerel are distributed in the inshore side of the oceanic fronts. However, in spring they are densely distributed near the warm-water front in the perturbed area between the Kuroshio and the Oyashio currents.

3.1.6.2 Induction of spawning

Chub mackerel became sexually mature under laboratory conditions and were induced to spawn with hormone injections (gonadotropines from salmon pituitary, pregnant mare serum and human chorionic). However, these hormones did not induce spawning when used individually (Leong, 1977).

3.2 Preadult phase

3.2.1 Embryonic phase

The chub mackerel egg has been described by Fry (1936a) and Orton (1953) from live material for the eastern Central Pacific Ocean. Kramer (1960) described the egg in greater detail from preserved material from the same area. Descriptions of eggs from the northwestern Pacific are provided by Uchida *et al.* (1958; quoted by Schaefer, 1980), Dekhnik (1959; quoted by Schaefer, 1980), Watanabe (1970) and Kuroda *et al.* (1982). Demir (1961) describes the eggs and larvae from the Sea of Marmara. Olivar and Fortuño (1991) also describe the eggs and larvae of chub mackerel of the southeast Atlantic (Benguela Current Region) (Fig. 6).

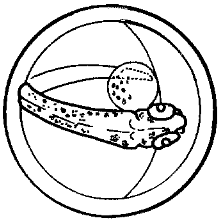
The eggs are spherical on average, ranging in diameter from 0.92 to 1.28 mm, with a 0.25 to 0.316 mm diameter oil globule (Fry, 1936a; Ahlstrom, 1956; Kramer, 1960; Demir, 1961; Watanabe, 1970; Ciechomski, 1971; Olivar & Fortuño, 1991). The eggs are transparent, and with the exception of their oil droplets, colourless (Demir, 1961). The shell of the egg is elastic and smooth and protects a homogeneous yolk with an oil droplet at its upper surface (Demir, 1961). The yolk is unsegmented and filled with a large number of tiny vacuoles when viewed under magnification (36x). The perivitelline space is narrow. In advanced stages of development, both the dorsum of the embryo and the oil globule are pigmented, the latter on the anterior hemisphere (Fry, 1936a; Kramer, 1960; Olivar & Fortuño, 1991).

Watanabe (1970) described three development stages for chub mackerel eggs. First, the stage from unfertilized condition to the closure of the blastopore in fertilized egg. Second, separation of the tail bud from the yolk as embryonic growth advances. And third, to hatching, when the cardiac pulse and locomotion of the embryo are observed. The period of embryonic development has been calculated in the laboratory as 53 to 56 hours at 18 to 20°C (Hunter & Kimbrell, 1980; Ciechomski, 1971).

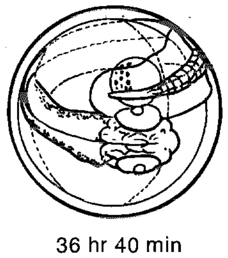
Around Japan, Watanabe (1970) observed that eggs are more abundant in the upper 50 m. The majority of eggs are probably located towards the upper layer within a few hours after spawning whereas hatched eggs tend to sink.

3.2.2 Larval phase

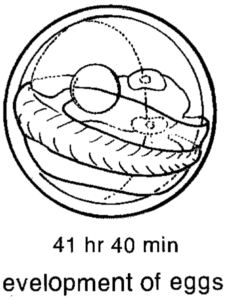
The development of the larvae and young stages of chub mackerel is described by Fry (1936a), Orton (1953), Uchida *et al.* (1958; quoted by Schaefer, 1980), Dekhnik (1959; quoted by Schaefer, 1980), Kramer (1960), Demir (1961), Watanabe (1970), Berrien (1978), Matsuura & Sato (1981), Belyaev & Rygalov (1987) and Olivar & Fortuño (1991) (Fig. 7a,b,c).



33 hr 40 min



36 hr 40 min



41 hr 40 min

Figure 6. Development of eggs of *Scomber japonicus* approximately 33, 36 and 41 hours after fertilization
(after Olivar & Fortuño, 1991)

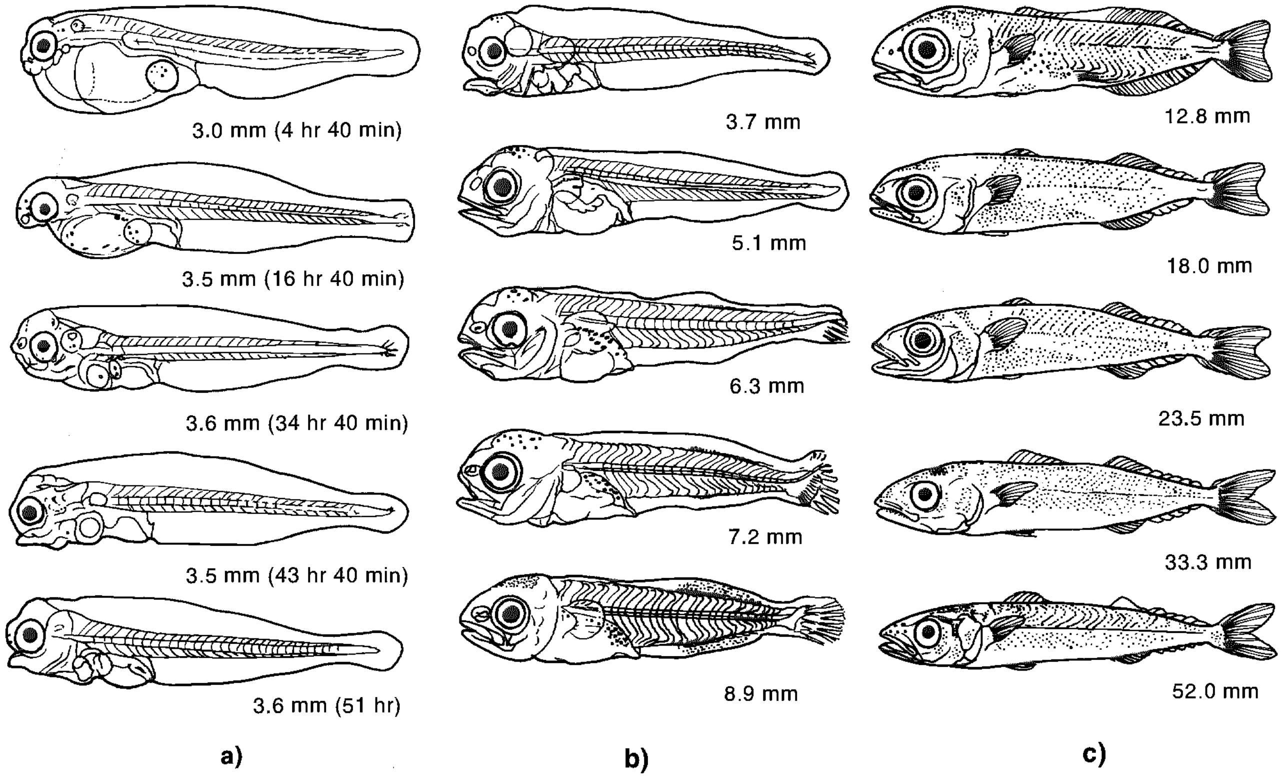


Figure 7. Development of larvae and young stages of chub mackerel

(after Watanabe, 1970)

At hatching, larvae average 3.1 mm SL (Berrien, 1978; Hunter & Kimbrell, 1980). The prelarvae (2.0 to 3.7 mm TL) has well developed fin folds and seldom swims, but rests in mid-water in a ventral position with the oil globule in the up side and the head obliquely down. The position of the anus shifts anteriorly as the yolk and the oil globule are absorbed. During the prelarval stage, some remarkable morphological changes take place, such as the appearance of the pectoral fin, the torsion of the alimentary canal, and the differentiation of the operculum and oral organs (Watanabe, 1970). Ossification occurs very soon after hatching, beginning with the cleithrum and parasphenoid bones, then the premaxillaries, mandibles and teeth. Teeth appear first on the anterior section of the premaxillaries and mandibles, at a length of about 3.5 mm, almost at the same time as the yolk sac is absorbed (Kramer, 1960).

The postlarvae (3.5 to 15.0 mm) has complete eye pigmentation and an open mouth. These young fish are already capable of swimming in the horizontal posture. Complete absorption of the oil globule and appearance of the primitive caudal fin ray occur at 3.5 to 4.0 mm, while the appearance of the primitive bases of the first dorsal, second dorsal and anal fins occur at 4.0 to 5.5 mm. Rays appear on the second dorsal, anal and pelvic fins at 5.5 to 8.5 mm; a consistent number of fin spines and rays is reached 8.5 to 15.0 mm. The chub mackerel begins to feed as soon as its mouth opens (Watanabe, 1970; Berrien, 1978). The first feeding occurs 46 hours after hatching and all larvae have fed after 60 hours (age 2.5 days). Starvation is irreversible if larvae do not feed before 4.5 days of age (Hunter & Kimbrell, 1980). Metamorphosis occurs at 15.0 mm, and takes place after 24 days at 16.8°C or 16 days at 22.1°C. Swimming speeds ranges from 1.3 SL per second for first-feeding larvae to 3.8 SL per second for fish at metamorphosis (Hunter & Kimbrell, 1980).

Watanabe (1970) found that prelarvae are uniformly distributed in the upper 50 m, while post-larvae scarcely inhabit depths of over 25 m. The post-larvae occur more abundantly near the surface at night than in the daytime. In the northwest Atlantic, larvae occur at water temperatures of between 16.0°C and 29.4°C (Berrien, 1978), whilst off Brazil, larvae are found between 20.4°C and 24.2°C (Matsuura & Sato, 1981). Ahlstrom (1959) and Kramer (1960) reported that off California, larvae were found at temperatures between 14.0°C and 21.9°C, while in the Gulf of California the major concentrations of larvae appear to occur between the surface isotherms of 20.5°C and 21.5°C with virtually no larvae collected at temperatures in excess of 22°C (Olvera-Limas, 1975). Esqueda-Escarcega (1995) found that larvae were distributed mainly in the north and central regions of the Gulf of California at sea surface temperatures between 16° and 22°C.

3.2.3 Adolescent phase

Watanabe (1970) defined fish between 1.5 and 5.0 cm TL as juveniles (Fig. 7a,b,c). In this stage, the number of fin spines and rays is consistent for the species. Swimming capacity increases so that fish are seldom taken by vertical hauls of small-sized plankton nets. The shift of the anus almost terminates and maculation begins to appear on the body surface at 3.0 cm in TL. At the same time, the fish acquire schooling behaviour. The young at 5.0 cm TL resemble well-formed scombriform fish as each fin becomes independent once the membranes between them disappear (Watanabe, 1970). The gill rakers are completely developed at 7 to 9 cm of length (Yasuda & Hiyama, 1957).

Fry (1936b) reports collecting chub mackerel a few months old close to the shore from Monterey, California, to Cabo San Lucas, Baja California. However, Watanabe (1970) reported that juvenile of 1.5 to 3.0 cm TL are sometimes collected in very large numbers at night. Fish of 3.0 to 5.0 cm TL seem to form pelagic schools and are attracted to light during night. Young fish (over 5 cm TL) sometimes migrate in schools towards the shore.

Castro & Lorenzo (1991) found that off the Canary Islands, the young (under 14.0 cm TL) inhabit shallow coastal waters and are caught together with juveniles of other fish species of a similar size, such as ***Sardina pilchardus***, ***Boops boops*** and Atherina presbyter. According to Castro (1991), juveniles of chub mackerel form mixed shoals with fish of similar size from those species previously mentioned.

3.3 Adult phase

The adult phase starts from the moment that the fish initiate sexual maturity in order to verify the first spawning (see point 3.1.2 Maturity). The length of first maturity varies between geographical areas, and is smaller in warmer regions. The adult fish undergo a significant increase in volume, especially during the spawning period (Lorenzo, 1992).

3.3.1 Longevity

Maxim *et al.* (1990) observed that the maximum age for these fish was 10 years during 1988 in northwest Africa. However, Krivospitchenko (1980) reported the maximum age as 18 years. In the South African purse-seine fishery, the oldest chub mackerel landed from 1964 to 1976 was 8 years old (Crawford, 1981b). Perrotta & Pertierra (1993) found that the oldest fish caught in the waters of Argentina was 12 years old.

Fitch (1951; 1952; 1953), based on otolith readings of chub mackerel from southern California caught from 1939-1940 to 1950-1951, found the oldest fish to be 12 years old. Gluyas-Millán & Muñoz-Gómez (1993) reported that the oldest fish caught off Vizcaino Bay (Mexico) was 8 years old. The oldest fish in Peru was 10 years old (Schaefer, 1980). However, the maximum age of fish in this region may be 9 years old (Kotlyar & Abramov, 1983; Serra, 1983). In Japan, the oldest fish caught was 11 years old (Watanabe, 1970).

3.3.2 Hardiness

Kramer (1969) reports that chub mackerel kept in aquaria do best in circular plastic-lined tanks. Gregory (1977), quoted by Schaefer (1980), conducted 15-day experiments with both tagged and untagged fish in ship's bait tanks to investigate the causes of tagging mortality. Leong (1977), who reported on the techniques for maturation and induced spawning of chub mackerel, kept them in tanks for over two years.

3.3.3 Competitors

Off the Mid Dalmatian islands (Adriatic), chub mackerel are often associated with ***Trachurus* sp.**, and small specimens are frequently found with sardine and anchovy Mužinic (1981). The diet of chub mackerel partially overlaps with ***Atherina presbyter, Sardina pilchardus, Sardinella aurita*** and ***Boops boops*** (Moreno & Castro 1995; Moreno, 1999). Off the Canary Islands, the adults are caught at night by luring them with lights and using purse seine, and are caught together with ***Trachurus* spp., *S. pilchardus*, *Sardinella aurita*** and ***B. boops***. Belvèze (1986) observed that off Morocco, increases in catches of chub mackerel, horse mackerel (***Trachurus* spp.**) and European anchovy (***Engraulis encrasicolus***) during 1976-1978 and 1981-1982 coincided with a decline in catches of sardine (***S. pilchardus***).

Off South Africa, young are often found in association with adult round herring (***Etrumeus teres***) (Baird, 1975; 1978a; Geldenhuys, 1978), which display similar behaviour (Crawford, 1981a).

Di Bussolo (1983), observed that adults of anchoita (***Engraulis anchoita***) and juvenile chub mackerel from south of Cabo San Antonio (Argentina) were feeding on the same class of food item, and had the same grade of stomach fullness.

Kramer (1969) states that chub mackerel in the eastern Central Pacific may compete for food with ***Trachurus symmetricus***. MacCall *et al.* (1976; quoted by Schaefer, 1980) suggest that ***Sarda chiliensis*** is a likely competitor. Claramunt-Quiñones & Fuenzalida-Fuenzalida (1989) reported that the abundance of ***Sarda chiliensis*** increases when the abundance of chub mackerel decreases. In the opinion of these authors, this may be related to competition for food between both species, in accordance with data recorded by Ojeda & Jaksic (1979) and Serra *et al.* (1979).

Watanabe (1970) observed that chub mackerel post-larvae are mixed together with postlarvae of ***Engraulis japonica, Trachurus japonicus, Seriola quinqueradiata, Cololabis saira*** and ***Todarodes pacificus*** while they are translocated downstream, but he indicates that food competition will most probably take place between ***Engraulis japonica*** and chub mackerel. Chub mackerel mostly inhabit the Kuroshio current and feed in the mixing zone. On the other hand, saury (***Cololabis saira***) are mainly distributed north of the Oyashio current and the retreat of this current pushes them further offshore where they cannot use the abundant plankton available in coastal waters. In spring, sauries and mackerels mix and are densely distributed near the warm-water front in the perturbed area between the Kuroshio and the Oyashio currents (Kosaka & Hirai, 1988). Tanaka (1983) reported that increases in chub mackerel catches in the period 1965-1978 took place concurrently with a decline in catches of saury and Japanese horse mackerel (***Trachurus japonicus***). Kawasaki (1971a) concluded that this caused a switch in distribution between saury and chub mackerel.

3.3.4 Predators

Artüz (1963) reported that chub mackerel was part of the diet of ***Xiphias gladius*** in the Sea of Marmara (Turkey). Hernández-García (1995a) found that off the Canary Islands chub mackerel were frequent in the stomach contents of various sharks (***Prionace glauca***, ***Sphyrna zygaena*** and ***Isurus*** sp.). In this area, tuna are the main predators of chub mackerel. Ramos *et al.* (1990) and Olaso *et al.* (1992) observed that ***Scomber japonicus*** represented between 12 and 70% of the diet of skipjack tuna ***Katsuwonus pelamis***. In northwest Africa, ***X. gladius***, ***Makaira nigricans*** and ***Tetrapturus albidus*** also feed on chub mackerel (Hernández-García, 1995a; 1995b).

In the southwest Atlantic, ***Thunnus albacares***, ***Coryphaena hippurus***, ***Istiophorus platypterus*** and ***Katsuwonus pelamis*** are the main predators of ***Scomber japonicus*** (Angelescu, 1979; Zavala-Camin & Seckendorff, 1980; Zavala-Camin, 1982; Ankenbrandt, 1985; Seckendorff & Zavala-Camin, 1985).

Zverson (1971, quoted by Schaefer, 1980), Pinkas (1962) and Matthews *et al.* (1977) found chub mackerel in the stomachs of albacore (***Thunnus alalunga***), and bluefin tuna (***T. thynnus***) from southern California and northern Baja California, respectively. Evans & Wares (1972) and Eldridge & Hares (1974) (both quoted by Schaefer, 1980) recorded the occurrence of chub mackerel in the stomachs of striped marlin (***Tetrapturus audax***) and sailfish (***Istiophorus platypterus***) from off the coastline of Buena Vista, Baja California. Off California, chub mackerel are preyed upon by sea lions (***Zalophus californianus***), white seabass (***Cynoscion nobilis***), yellowtail (***Seriola dorsalis***, ***S. lalandi***), giant sea bass (***Stereolepis gigas***), and sharks (Frey, 1971; Collette & Naue, 1983). Gress *et al.* (1980; quoted by Schaefer, 1980) reported chub mackerel in the diet of the California brown pelican (***Pelecanus occidentalis californicus***) using regurgitated stomach contents of young pelicans at Anacapa Island (California, USA). In the Gulf of California, Velarde *et al.* (1994) found mackerel in the diet of Heermann gull (***Larus heermanni***) and the elegant tern (***Sterna elegans***). Hernández-Trujillo & Esqueda-Escarcega (1994) reported the copepod ***Candacia curta*** preying on larvae of chub mackerel in the Gulf of California (Mexico).

Fuentes *et al.* (1989) recorded chub mackerel in the stomach contents of ***Merluccius gayi peruanus*** in waters of Paita (Peru). In northern Chile, Ojeda & Jaksic (1979) found that large-sized ***Sarda sarda chiliensis*** feed almost exclusively on chub mackerel.

Morita (1960; quoted by Schaefer, 1980) reported ***Scomber*** **sp.**, probably chub mackerel, to be one of the most important food items of the black marlin (***Makaira indica***) in the East China Sea. Chub mackerel is a prey for minke whales (***Balaenoptera acutorostrata***) off the Pacific coast of Hokkaido (Japan) (Kasamatsu & Tanaka, 1992).

- Camouflage and evasive behaviour

Waves create an ever-changing series of light and dark spatial patterns underwater. However, these patterns are not visible unless a reflective object is present. Simple periodic waves, as from a spreading ripple, produce very organized patterns. According to McFarland & Loew (1983), in the ocean, simple waves patterns mix to produce complex patterns that are surprisingly similar to the dorsal marking observed on mackerel and other fish-like tunas, barracuda, etc. These authors point out that often, these fishes feed and remain close to the surface throughout the day. Viewed from above, as by a predatory bird or fish, they merge with the bottom because their silvery backs flicker in synchrony with the wave-induced light fluctuation displayed on the sand. When viewed from the side, however, they are obvious because the light pattern flicks along their backs against the non-flickering background. Seen from below these non-counter-shaded fishes may or may not flicker against the oscillating surface, dependent on sun angle and depth. When threatened these fishes employ a specific evasive behaviour consisting of moving to the surface. By doing so, they literally merge with the flickering surface and are extremely difficult to fixate, let alone see. Only their dark eyes offer an obvious target.

3.3.5 Parasites, diseases, injuries and abnormalities

Lists of chub mackerel parasites found in different parts of the world are given by Silas (1967), Silas & Ummerkutty (1967), Cressey & Cressey (1980) and Cressey *et al.* (1983) (Table 4). Atli (1960) found nematodes in the gonads of chub mackerel from the Sea of Marmara. This author reported that the parasite ***Acantocephalus*** was always found in the stomach contents of chub mackerel, sometimes in amounts of over 50 individuals in one stomach. Off northernf Chile, Díaz-Ocampo found that 41.6% of mature female chub mackerel had gonads parasitised by trematodes of the genus ***Nematobothrium***.

In the Atlantic, Arandas-Rego (1987) and Eiras & Arandas-Rego (1987) found traces of acanthocephalans and trematodes in chub mackerel off Portugal. Along the Namibian coast, Wysokinski *et al.* (1987) found three groups of parasites, nematoda, cestoda and microsporidia. ***Anisakis* sp.** caused the highest level of infestation on internal organs, with an average incidence of 91% and reaching 100% in fish over 60 cm long. The intensity of infestation was high with an average of 8.8 and a maximum of 41 parasites per specimen. However, tapeworm infestation was insignificant. Wysokinski *et al.* (1987) found only 1 to 3 tapeworms in the intestine of 15 out of 170 specimens sampled. Other unidentified parasites in 2 out of 74 fish were a large number of small grains in the spiral muscle, and inside and between myomeres. These authors did not find parasites on the gills of chub mackerel.

Cremonte & Sardella (1997) reported that off Argentina 94.75% of the chub mackerel were infected. They also discussed the possibility of using some parasites as ecological tags for the geographical areas of Mar del Plata (37 to 38°S) and El Rincón (39 to 41°S).

Off Chile, Díaz-Ocampo (1991), found that the percentage of fish infected by ***Nematobothrium*** increased with size, from 30.5% in the size range of 26 cm, to 61.5% in the size range over 35 cm.

Chub mackerel develops hyperplasia (cancer-like growths) on the head skin when raised in captivity (Kramer, 1969). Leong (1977) reported that chub mackerel held in seawater tanks at 19°C developed malformed jaws after 4 months, then became unable to feed and finally died.

Papadopoulou & Kanias (1978) reported that the zinc contents in otoliths of chub mackerel from the Aegean Sea (eastern Mediterranean Sea) was a linear function of age and body length. In addition, Papadopoulou & Kanias (1980) found caesium, iron, selenium and silver in otoliths. Nevertheless, the content of these elements decreased with age. Quintero & Díaz (1994a; b) found polycyclic, aromatic and aliphatic hydrocarbons in chub mackerel caught off the Canary Islands (eastern Central Atlantic).

During November 1992, an intense bloom of the toxic dinoflagellate ***Alexandrium tamarense*** occurred off the coast of the Mar del Plata (Argentina). Carreto *et al.* (1993) found that the liver extract of chub mackerel was lethal for mice, which suggested that this fish accumulates paralytic shellfish poisoning toxins from its food. Paralytic poisoning toxin concentration (39 µg STXeq/100 g tissue) was below the established limit for human consumption.

Table 4. Food composition of *Scomber japonicus* (in % of weight) by geographic areas

	CANARY ISLANDS (Castro,1993)	N.W. AFRICA (Weib, 1974)	SOUTH AFRICA (Baird, 1978)	ARGENTINA (Pajaro, 1993)	JAPAN (Hatanaka *et al.*, 1957)	JAPAN (Yasuda, 1960a)	PERU (Konchina, 1982)
Fish	3.5-47.6	0.0-2.0	13.5-52.5	2.5-37.1	0.9-100	33.0-75.0	2.8
Cephalopods	0.4-2.4	0.0-2.0	0.01	-	1.3-36.6	2.0	6.5
Molluscs	0.4-2.0	0.0-20.0	-	-	-	-	18.8
Euphausiids	0.2-4.4	30.0	16.5-42.6	4.3	1.3-56.3	-	35.5
Mysids	14.7-36.2	20.0-25.0	0.01	-	-	13.0-33.0	0.5
Decapods	2.7-6.9	0.0-2.0	0.7-1.2	2.7-63.8	8.3-73.4	8.0	5.3
Copepods	7.4-26.6	30.0	0.2-8.1	1.4-35.1	-	3.0	18.2
Amphipods	3.6-9.2	-	3.6-30.0	2.7-16.7	1.1-5.2	1.0	0.3
Ostracods	0.8-2.7	0.0-2.0	-	-	-	-	0.0
Chaetognaths	0.2-1.7	0.0-2.0	0.8	-	-	4.0-6.0	2.1
Appendicularians	1.1-6.9	-	-	-	-	-	0.0
Phytoplankton	0.0	5.0-10.0	-	-	-	-	0.0
Others	2.7-9.1	0.0-3.0	12.8-30.0	2.8-31.1	0.6-38.2	16.0	10.8

3.4. Nutrition and growth

3.4.1 Feeding

3.4.1.1 Food Intake

Hatanaka *et al.* (1957), found that the amount of food ingested by juvenile and adult fish varied between 0 and 16% of their body weight. However, Angelescu (1979) recorded ranges of stomach repletion from 5 to 22%. Hatanaka & Takahashi (1956) reported that mackerel held in aquaria and fed with anchovy, consumed up to 24% of their body weight per day for fish of about 7 g, but that the consumption rate diminished gradually with growth and stabilized at 10% of the body weight for fish 20 to 50 g. In the Sea of Japan, the periods of maximum stomach fullness are related to the presence of larvae and postlarvae of fish in the diet. Tarverdieva (1985) reported that in the southeast Atlantic in waters 15 to 16°C, a fish of 51.8 cm and 2.160 g consumed daily 340 g of food (15.8% of the body weight). The predator-prey size relationship shows values between 33 and 43% for chub mackerel feeding on adult anchovy (Angelescu, 1979).

Chub mackerel under one year old require 8% of their body weight in food daily (if the diet is only crustaceans), in order to maintain their natural growth rate which is over 0.42% of their body weight daily (Hatanaka *et al.*, 1957; O'Connell & Zweifel, 1972). Hatanaka & Takahashi (1956) indicated that when feeding on anchovy, mackerel could barely maintain their weight on a daily ration of close to 3.5% body weight (1.8% in caloric equivalence). These authors also recorded a daily growth of up to 9% of the body weight for fish 6.8 cm in length and stable growth close to 2.4% for larger fish. At 12°C, food conversion efficiency was 39%. However, this rate diminished with growth and remained at about 25% for fish over 20 g in weight (12 cm in length). Konchina (1985) recorded that the food spectrum of chub mackerel appeared to provide higher metabolic rates and weight increases and a more rapid linear growth as compared to the Pacific sardine (***Sardinops sagax caerulea***).

The highest food intake in starved fish was about 23% of the body weight and 16% on average when they were satiated with anchovy at about 20°C. The stomach contents decreased rapidly with time, reaching about 20% of the initial weight after 5 hours and 1.8% after 10 hours. Digestion was completed in 21 to 24 hours. The pH of the stomach contents was about 6.7 before feeding and decreased rapidly after feeding, reaching 4.1 after 7.5 hours (Kariya & Takahashi, 1969).

Razniewski (1967) reported that off Northwest Africa, chub mackerels feed continuously, even during the spawning season. However, Habashi *et al.* (1987) indicated that the feeding intensity decreases somewhat during spawning. Weib (1974) observed that the main feeding time was between the afternoon and the first hours after dusk. Tarverdieva (1985) reported that in the southeast Atlantic, the highest and lowest feeding activity was at 1800 to 2000 hours and 0400 to 0600 hours, respectively. In contrast, Angelescu (1979) observed that the period of major feeding activity off Argentina, was during the first hours after sunrise. Nevertheless, this author reported that until 1000 hours the stomachs were found empty or with little food digested or recently ingested. Mendoza (1993) estimated that food intake by the population of chub mackerel in waters of northeastern Venezuela (24 000 t) was 7.22 t/km^2/year, assimilation was estimated to be 40.56 t/km^2/year, respiration was 37.56 t/km^2/ year, and the net efficiency 0.09.

3.4.1.2 Intestinal microflora

Sugita *et al.* (1989) report on the intestinal bacteria found in chub mackerel from Japan. The types of intestinal microflora were, in order of importance, ***Vibrio, Pseudomonas, Bacillus, Flavobacterium, Acinetobacter***, yeasts and ***Clostridium***.

3.4.2 Food

3.4.2.1 Diet of larvae

Hunter & Kimbrell (1980) observed that in the laboratory larvae prey on copepods or rotifers, and often attack the same prey more than once when previous attacks have not been successful. According to these authors, at 8.1 mm SL, most mackerel larvae were able to capture and ingest yolked larvae of Peruvian anchovy (***Engraulis ringens***). From 8 mm onwards, cannibalism occured. Larvae of 10.8 mm SL were able to prey on others 6.2 mm SL. Fifty-nine percent of all the prey identified in the stomachs of wild larvae were copepods, with the remainder made up of cladocerans, appendicularians, gastropod larvae, eggs of invertebrates, diatoms, faecal pellets and, very rarely, fish larvae. In the southeast Pacific, Lipskaya (1982) recorded larvae feeding almost exclusively on appendicularians (64 to 100%) and fish larvae, including those of their own species. Cannibalism was recorded particularly in spawning grounds where, due to prolonged spawning, both newly hatched and advanced larvae were present. Ozawa *et al.* (1991) observed that in waters off Japan, larvae fed mainly on appendicularians, crustacean eggs, copepods, cladocerans, and in some cases, fish larvae. Chub mackerel larvae (age 3 to 5 days) consumed an average of about 87% of their dry body weight per day, or about 165 to 538 rotifers per day (Hunter & Kimbrell, 1980).

3.4.2.2 Diet of juveniles

Off the Canary Islands, juvenile chub mackerel (3 to 13 cm TL), feed mainly on zooplankton, but larvae and juveniles of other fish species are also very important. Juveniles 14 to 18 cm TL have a diet based on large-sized zooplankton. Mysids, euphausids and decapod larvae are highly significant in the diet during summer and autumn, while copepods and fish are most important during the winter and spring (Castro, 1991; 1993; 1995). It is highly probable that the change in diet observed between 12 and 15 cm TL off the Canary Islands (Castro, 1993), is related to a change in habitat. This process leaves a mark on the hard structures used for assessing growth in the fish (Lorenzo, 1992; Castro & Hernández-García, 1995). This migration was also observed by Sánchez (1982) off Argentina. Crawford (1981b) pointed out the possibility of the possible importance of the myctophid (***Lampanyctodes hectoris***) in the diet of 0-year-old fish as one of the causes of the migration of this size of fish towards deep waters in South Africa.

Off South Africa, 13.5% of the diet of fish under 25 cm, is made up of fish ranked third in importance (Baird 1978b). The other 86.5% is made up of zooplankton, with 42.6% of this consisting of ***Euphausia lucens***, ***Nyctiphanes capensis***, and euphausid larvae. Thirty percent of the zooplankton were made up of amphipods, and the rest by copepods, other crustaceans, tunicates, mollusks and chaetognaths. The importance of zooplankton decreases with increasing fish size. According to this author, fish under 25 cm preys on zooplankton in the surface layers.

Angelescu (1979; 1980) found that in the southwest Atlantic, along the coast of Argentina, copepods, sergestids and anchoita postlarvae and juvenile (***Engraulis anchoita***) dominate in the diet of juvenile mackerel. In the Uruguayan shelf, Goberna (1987) observed that the diet of juvenile mackerel was made up mainly of copepods, cladocerans, decapod larvae, chaetognaths and fish.

Kishinouye (1923) observed that in the Pacific Ocean, juvenile mackerel prey on juvenile of other fish species especially ***Engraulis japonica*** (Hatanaka & Takahashi, 1956). Hatanaka *et al.* (1957) found that juvenile mackerel caught in the coastal regions of the Sea of Japan, prey mainly on crustaceans, especially ***Euphausia* spp.**, during April to mid-July. Later on until mid-October, they prey on fish, mainly anchovy, but also sardines, jack mackerel and squids.

3.4.2.3 Diet of adults

Mysids, euphausids and decapod larvae constituted almost 50% of the biomass in the diet of adult chub mackerel (over 20 cm) in the Canary Islands (Castro, 1993). This coincides with data reported by Takahashi (1966) off Japan. In the Canary Islands, mysids replaced euphausids in their importance on the diet of adult chub mackerel, despite the fact that the opposite was most common over the world (Table 5); fish, amphipods and copepods comprised 3.1, 1.8 and 36.8% of the diet respectively (Castro, 1993). In northwest Africa Habashi & Wojciechowski (1973) found that the whole range of chub mackerel sizes available (15 to 50 cm TL) fed on copepods and euphausids. Larger fish also feed on decapods, chaetognaths, tunicates, cephalopods and small fish. The cephalopods were most frequent in the diet of mackerels caught off Morocco and the Western Sahara. ***Branchiostoma lanceolatum*** and small fish, like ***Sardina pilchardus***, were found in fish caught near the shore, while ***Maurolicus mulleri*** was found in individuals caught offshore. Domanevsky (1970) observed that chub mackerel fed on zooplankton, jellyfish and small squids and fish, especially the European anchovy (***Engraulis encrasicolus***). Weib (1974), found that the diet of fish 24 to 30 cm long was based on copepods and euphausids, while all fish between 30 and 37 cm fed on large prey, such as tunicates, decapods, fish and benthic fauna. Weib (1974) also found important quantities of phytoplankton in the diet of chub mackerel. Falk (1967) found sediment, especially foraminifera and remains of shells, in the stomach contents of chub mackerel, although other samples showed live organisms such as amphipods, tunicates, copepods, euphausids, small fish and cephalopods. According to this author, the chub mackerel is not strictly a plankton feeder but sometimes eats sediment and probably combines planktophagous and detritivorous habits. An alternative may be that chub mackerel swallow sediments due to the fishing gear (bottom trawl), as occurs with the scales they swallow when caught by purse seine. Notably, Falk's data show that juvenile of ***Solea* spp.** were found together with the sediment in some stomach contents.

Baird (1978b) found that fish constitute 13.5%, euphausids 42.6%, amphipods 30% and copepods 0.2% in the diet of chub mackerel less than 25 cm long in the waters of South Africa. For chub mackerel 26 to 45 cm, fish between 4.6 and 10.4 cm TL represented 33.5% of the diet. ***Lampanyctodes hectoris***, ***Engraulis capensis*** and ***Etrumeus witheady*** were the predominant fish species. For large mackerel (over 46 cm), fish represented the basis of the diet (52.5%). The most common species ***Lampanyctodes hectoris*** constituted 44.4% of the total. The presence of other fish species was insignificant. In the zooplankton, the biomass of euphausids (***Euphausia lucens***, ***Nyctiphanes capensis*** and ***N. furcilias***) played a predominant role in the diet of adults 26 to 45 cm and over 46 cm, representing 16.5 and 30.3%, respectively. Crawford & De Villiers (1984) pointed out that predation of chub mackerel on ***E. capensis*** is the main cause of the high natural mortality of the latter.

In the shelf and coastal waters of Argentina, Angelescu (1979, 1980) and Pájaro (1993) reported that the diet of chub mackerel was highly flexible, both in the taxa eaten (over 20 species of food) and in the size range of food items (from 1 mm up to 140 mm). The main food items were planktonic crustaceans, especially copepods, and fish, specially anchoita, as well as squid (***Loligo sanpaulensis***). Angelescu & Fuster de Plaza (1962) estimated that one chub mackerel

Table 5. List of parasites of *Scomber japonicus*

SPECIES	LOCATION	LOCALITY	REFERENCE
TREMATODA			
Dactylogyrus inversus	Gills	Japan	Silas, 1967
Kuhnia scombri	Gills	Mediterranean, NW Atlantic, Japan, Chile, Argentina	Silas, 1967;Villalba & Fernández, 1986; Cremonte & Sardella, 1997
K. minor	Gills	Japan	Silas, 1967
K. macracanthus	Gills	Galapagos Islands	Silas, 1967
Gastrocotyle japonicus	Gills	Japan	Silas, 1967
G. dillonhargisi	Gills	SW Australia	Lebedev, 1980
Didymozoon longicolle	Gills		Silas, 1967
Allonematobothrioides baueri	Gills	NW Pacfic	Nikolaeva & Tkachuk, 1986
Nematobothrium filiforme	Gills	Japan	Silas, 1967
N. scombri	Bucal cavity, gills	Mediterranean, NE Atlantic, Pacific	Silas, 1967; Eiras & Arandas-Rego, 1987
Nematobothrium sp.	Gonads	Chile, Argentina	Díaz-Ocampo, 1991; Cremonte & Sardella, 1997
Tergestia laticollis	IntestineIntestine	Japan, Florida	Silas, 1967
T. acanthocephala	Intestine	Japan	Silas, 1967
Aphallus tubaium	Intestine	Mediterranean	Silas, 1967
Lepocradium retrusum	Intestine	NW Atlantic	Silas, 1967
L. misakiense sp.	Intestine	Japan	Shimazu, 1986
Opechona olssoni	Stomach, intestine	Japan	Silas, 1967; Shimazu, 1986
O. orientalis	Stomach, intestine	W Pacific, Galapagos Islands	Silas, 1967
O. bacillaris	Intestine, pyloric caeca	Mediterranean, Atlantic	Silas, 1967
O. scombri	Intestine, pyloric caeca	Japan, Indonesia	Silas, 1967; Shimazu, 1989
Opechona spp.		Argentina	Cremonte & Sardella, 1997
Dinurus scombri	Stomach	Japan, Florida	Silas, 1967
Ectenurus lepidus	Stomach	Mediterranean	Silas, 1967
Lecithocladium excisum	Stomach	Atlantic, Pacific, New Zealand	Silas, 1967; Belyaev & Ryabov, 1987
L. gulosum	Stomach	NW Atlantic	Silas, 1967
Eyelavera parukhini sp.nov.	Gills	SW Australia	Lebedev, 1980
CESTODA			
Hepatoxylon trichiuri	Body cavity	Namibia	Wysokinski *et al.*, 1987
Scolex pleuronectis		Argentina	Cremonte & Sardella, 1997
ACANTHOCEPHALA			
Corynosoma australe		Argentina	Cremonte & Sardella, 1997
NEMATODA			
Acantocephalus	Stomach	Sea of Marmara	Atli, 1960
?	Gonads	Sea of Marmara	Atli, 1960
Rhadinorhynchus pristis		Portugal	Arandas-Rego, 1987
R. trachuri		NW Pacific	Belyaev & Ryabov, 1987
Telosentis tenuicornis		Portugal	Arandas-Rego, 1987
Anisakis spp.	Internal organs	Namibia, NW Pacific, Yellow Sea, Argentina	Wysokinski *et al.*, 1987; Belyaev & Rayabov, 1987; Sizheng *et al.*, 1993; Cremonte & Sardella, 1997
Thynnascaris	Stomach, body cavity	NW Pacific	Sakaguchi *et al.*, 1980
Histerothylacium spp.		Argentina	Cremonte & Sardella, 1997
Contracaecum spp.		Argentina	Cremonte & Sardella, 1997
Pseudoterranova spp.		Argentina	Cremonte & Sardella, 1997

Table 5. (continued)

SPECIES	LOCATION	LOCALITY	REFERENCE
COPEPODA			
Caligus productus	Gills, body surface	Baja California (Mexico)	Silas & Ummerkutty, 1967
C. infestants		Indonesia	Silas & Ummerkutty, 1967
Clavellisa scombri	Gills	Mediterranean, Japan	Silas & Ummerkutty, 1967
Clavellopsis saba	Gills	Japan	Silas & Ummerkutty, 1967
Lepeophtheirus dissimulatus	Outer surface of body	E Pacific	Silas & Ummerkutty, 1967
MICROSPORIDIA			
?		Namibia	Wysokinski *et al.*, 1987
ISOPODA			
Ceratothoa gaudichaudii	Gills, bucal cavity	California	Anon., 1990

consumed between 15 and 32 juvenile anchoita daily. Angelescu (1979) and Pájaro (1993) observed evidences of cannibalism. The feeding habits appear to be mixed in types of food items and strategies for obtaining food, with plankton feeders having a filtering process, and small carnivorous catching prey. Chub mackerel is representative of an opportunistic feeder, with a tendency towards euriphagy: in other words, planktophagous-carcinophagous or ichthyophagous (Angelescu & Fuster de Plaza, 1962; Angelescu, 1979; Pájaro, 1993).

Fry (1936b) observed that off California, the diet of the adult chub mackerel was made up of a great number of items (fish, squids and small crustaceans like copepods), but he never found mixtures of these. According to this author, chub mackerel are very voracious, feeding on whatever material, dead or alive, they find within their range. Fitch (1956) indicated that 30% of the stomach content volume was made up of larvae and juvenile fish, and the remainder of mysids, copepods and euphausids. This is in agreement with the results obtained by Molina *et al.* (1996) in the Gulf of California. According to these authors, the main prey were fish larvae (***Engraulis mordax*** and ***Sardinops caeruleus***) followed by crustacean larvae (brachyurans and stomatopods) and calanoid copepods (***Calanus pacificus***, ***Acartia* sp.**, and ***Paracalanus* sp.**). Folkvord & Hunter (1986) concluded that chub mackerel are responsible for the high mortality of ***E. mordax***. Molina *et al.* (1996) suggest that chub mackerel adults employ filter-feeding because they have a small gill-raker gap, and that juveniles, which have a larger gill-raker gap, are particle-feeders.

Miñano & Castillo (1971), and Ojeda & Jaksic (1979), classified the chub mackerel off Peru and Chile as carnivorous, with a diet based mainly on fish, fish eggs, crustaceans (euphausids and copepods) and phytoplankton. The prey fish were Peruvian anchovy (***Engraulis ringens***), white anchovy (***Anchoa* sp.**), ***Brevoortia maculata***, Peruvian sardine (***Sardinops sagax sagax***), and juvenile chub mackerel. Böhm *et al.* (1984) also observed evidence of cannibalism, especially on eggs. Mendo (1984), found that the phytoplankton in the diet consisted mainly of diatoms, and was present in all the stomach contents analysed. Konchina (1982) pointed out that chub mackerels have a highly flexible diet and classified them as second-order predators, at the limit of the third trophic level. Their trophic spectrum included pelagic fauna of two different sizes: mesoplankton and macroplankton. He recorded 17 different taxa, highlighting the small pelagic fish. Muck & Sánchez (1987) estimated that during 1953-1982, mackerel was a more significant predator of anchovy than the guano birds, bonito or marine mammals, and that anchovy consumption by chub mackerel and southern jack mackerel (***Trachurus murphyi***) either exceeded or was similar to the fishery catches. The diet of chub mackerel included also siphonophores, salps, molluscs, polychaetes, copepods, euphausids, mysids, decapods, tunicates, chaetognaths, cephalopods and fish eggs and larvae (Konchina, 1982; 1990; 1992).

Takahashi (1966) observed that during July 1954, chub mackerel between 18 and 22 cm long fed mainly on ***Euphausia pacifica***. Only during the second half of July, some individuals preyed on Japanese anchovy (***Engraulis japonica***). Muyakshin & Selivanovsky (1995) observed, with the help of spectrograms (Doppler echo-sounding technique) the fast-swimming chub mackerel hunting less-active ***Engraulis japonicus***. Takahashi (1966) found a much lower number of sardines (***Sardinops melanosticta***) and Japanese horse mackerel (***Trachurus japonicus***) than anchovy in the stomach content of chub mackerel. The size range of anchovies eaten fluctuated between 26 and 36% of TL of mackerel, with the most extreme case standing at 50% of TL. The same relationship was found for the sardine and jack mackerel preyed. However, the most frequent size of jack

Table 6. Age-length relationships of *Scomber japonicus* by geographic areas (age determined from otolith, vertebra or scales)

LOCALITY	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	REFERENCE
OTOLITH												
Marmara Sea	14.80	18.10	20.50	22.20	22.60	26.30	32.60					Tuggaç, 1957
Black Sea	14.90	18.90	21.20	23.30	25.10	25.80	27.50					Atli, 1960
Spain (Cataluña)	23.10	24.80										Perrotta, 1993
Portugal (39°N)	21.99	27.06	31.33	34.92	37.93	40.46	42.59	44.38	45.89	47.26		Margins *et al.*, 1983
Spain (Cádiz)	22.40	26.42										Rodríguez-Roda, 1982
Portugal (37°N)	21.50	27.53	31.67	34.78	37.52	39.64	42.75					Martins & Serrano-Gordo, 1984
Azores	18.91	25.63	30.89	35.01	38.23	40.75	42.73	44.28	45.49	46.44		Westhaus-Ekau & Ekau, 1982
Canary Islands	20.30	25.90	30.70	34.80	37.00		42.10					Lorenzo, 1992
NW Africa	15.10	23.6	29.0	32.5	34.8	36.3	37.3					Domanevsky, 1970
NW Africa	20.00	26.00	33.0	36.50	39.50	43.20	47.20					Habashi & Wojciechowski, 1973
Mauritania		24.8	32.6	35.2	40.5							Holzlöhner & Kloxin, 1985
Senegal	20.40	25.00	29.75	34.00								Viskrebenzev, 1963
Gulf of Guinea	17.02	20.85	23.72	25.80								Viskrebenzev, 1963
SW Africa (C. Frio)	20.75	29.14	38.24	46.50	53.10							Viskrebenzev, 1963
Namibia	21.24	31.44	34.87									Viskrebenzev, 1970
Namibia			42.34	44.16	45.91	49.00	50.00					Morales & Sánchez, 1980
Namibia						55.3	57.5	58.5	60.5	62.5		ICSEAF, 1974-1987
Namibia	27.39	30.02	35.08	45.58	51.72	54.54	56.88	59.06	60.59	61.03	61.50	Ostapenko, 1988
South Africa	23.16	31.48	38.26	43.73	48.98	52.05	56.63	59.27				Baird, 1977
Brazil	21.00											Seckendorff & Zavala-Camin, 1985
Argentina	28.90	31.70	33.80	35.50	38.00	39.70	41.30	42.60				Gagliardi & Cousseau, 1970
Argentina	27.48	30.98	34.62	36.48	37.98	39.23	40.95	42.60				Castello & Cousseau, 1976
Argentina	26.80	31.19	33.86	36.06	38.00	39.74	41.27	42.63				Angelescu, 1979
Argentina	23.08	30.41	33.85	35.96	37.92	39.42	40.31	41.73	42.98	43.96		Perrotta, 1988c
Argentina	16.30	18.80	30.40	33.00	36.70	37.80	40.10	41.10	42.40	42.80	44.30	Perrotta, 1992
Argentina	25.25	29.73	33.35	35.86	37.94	38.91	39.50	40.75				Perrotta & Forciniti, 1994
Argentina	28.50	30.17	33.06	34.87	36.83	38.46	39.90		42.83			Perrotta & Forciniti, 1994
California	26.80	30.40	33.00	35.30	37.00	38.10	39.30	39.80				Fitch, 1951
California	22-39	24-39	28-41	28-40	32-41	33-42	33-43	36-43	39-42			Kramer, 1969

Table 6. (continued)

LOCALITY	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	REFERENCE
OTOLITH												
California	27.30	30.83	33.60	35.78	37.48	38.81	39.85	40.66				Knaggs & Parrish, 1973
East Russia	21.50	29.10	34.40	44.50	52.00							Slastenenko, 1955
Japan Sea	19.30	26.70	31.30	34.40	36.80							Belyaev & Ryabov, 1987
Japan Sea	19.90	27.70	34.40	35.10								Belyaev & Ryabov, 1987
Japan	20.40	26.20	31.00	34.20	36.60	39.90						Yoshida, 1955
Japan	11.80	18.20	23.70	29.08	33.72	37.61						Yoshida, 1955
Japan		26.00	30.50	33.50	36.50	39.00						Yoshihara, 1955
Japan	12.25	19.50	25.50	30.75	34.00	36.75	39.50					Tsuji & Hanamura, 1957
Japan	14.40	21.09	26.54	30.81	33.43	35.83	38.09	39.76				Yonemori & Aikawa, 1956
Japan	16-21	21-26										Hatanaka *et al.*, 1957
Japan	20.57	26.16	28.88	30.92	33.08	36.11						Alagarswami *et al.*, 1969
Taiwan	15.63	21.08	25.34	28.76	31.86	34.03	35.02					Zhenbin *et al.*, 1991
Ecuador	20.67	24.95	28.23	30.71	32.59	34.01	35.09	35.90	36.51	36.98		Pizarro de Rodríguez, 1983
Ecuador	18.0	25.7	29.1	29.9	31.3	33.0	34.7	31.2				Dawson, 1986
Peru	20.60	28.0	33.2	35.9	37.7,	40.7						Kotlya & Abramov, 1983
Peru	14.15	23.00	28.89	32.81	35.41	37.14	38.29					Mendo, 1984
Chile	15.30	19.55	23.30	26.49	29.21	31.52	33.48	35.15				Aguayo & Steffens, 1986
VERTEBRA												
Japan	<16	17-24	25-32	33-39	40-46	47-50						Aikawa, 1937
Japan	21.20	31.30	37.20	40.10								Yonemori & Aikawa, 1956
Japan	19.84	29.38	34.00									Kondo & Kuroda, 1966
Japan	19.12	23.95	27.76	30.80	33.22	36.12						Alagarswami *et al.*, 1969
SCALE												
NW Africa			28.67	31.62	34.30	36.66	38.76	40.59	42.25	43.69		Staicu & Maxim, 1974
Japan	22.5	31.0	34.90	37.60	39.10	41.20						Okachi, 1955
Japan	18.5	27.5	31.70	34.50	36.50	38.20						Kondo, 1966
Japan	18.97	27.65	32.31	35.27	37.25	38.58						Kondo & Kuroda, 1966
Japan	20.0	27.0	32.00	35.00	37.50	39.50	41.00					Iizuka, 1967
Japan	23.38	28.11	30.39	32.27	33.77	35.16						Alagarswami *et al.*, 1969
Japan	20.24	26.93	31.27	34.42	36.26							Ann, 1971

mackerel was around 18% of TL of chub mackerel, with 30% maximum. Nishimura (1959) reported that in the Sea of Japan, and from January to April (the demersal winter phase) chub mackerel fed on ***Euphausia pacifica, Metridia lucens, Parathemisto japonica, Calanus cristatus, Pashiphaea sivado, Pareuchaeta japonica***, pearlfish (Pisces: Carapidae) and anchovy. During the spawning period, the diet was based on salps and pearlfish. From July to December (pelagic migratory phase) chub mackerel fed on anchovy, juvenile jack mackerel and salps. Kasahara & Ito (1953), quoted by Hatanaka & Takahashi (1960), reported that chub mackerel fed on euphausids, copepods, amphipods, followed by fish like sardines, anchovies and small squids. Takano & Honado (1955; quoted by Hatanaka & Takahashi, 1960) concluded that anchovy is the main food item of chub mackerel followed by ***Euphausia pacifica*** and ***Calanus plumchrus***. Maeda *et al.* (1955; quoted by Hatana & Takahashi, 1960), pointed out that between 67 and 100% of the stomach content weight of mackerels caught between May and October in the Sea of Japan was anchovy and sardine. Nishimura & Okachi (1957; quoted by Hatana & Takahashi, 1960), affirmed that the diet of chub mackerel during February and March 1957 was based almost exclusively on ***Euphausia pacifica*** and rarely on anchovy or small squids. ***E. pacifica*** was also the main food of chub mackerel in the Yellow Sea (Kang, 1986). In the Taiwan Channel, the diet of chub mackerel was dominated by copepods, amphipods and small fish (Dai, 1989). Hatanaka *et al.* (1957), found that mackerel fed on anchovy during the summer and autumn in the coastal waters of Japan, and on pelagic crustaceans the rest of the year. Takano (1954) found that the mysid ***Gastrosaccus vulgaris*** was frequent in all samples and constituted the major part of the diet of chub mackerel in coastal waters close to the Oshima and Izu Islands. The remainder of the diet was made up of decapod larvae, amphipods, tunicates and juvenile fish. Yasuda (1960a; b), classified the chub mackerel as an omnivorous fish, with ichthyophagous or carnivorous habits as an adult.

3.4.3 Growth rate

Hunter & Kimbrell (1980) report on the growth and metabolism of chub mackerel larvae reared in captivity. They found that larvae growth in length is slow and almost linear over the first 10 to 15 days, until larvae reach about 6 to 7 mm SL. Subsequently, they have a relatively high metabolic rate and grow rapidly, completing metamorphosis at 1.5 cm in 2 to 3 weeks for a temperature range of 16.8 to 22.1°C. The growth of postlarva may be described by TL=3.50e0.0766t, where t is the number of days from the commencement of postlarval stage (Watanabe, 1970). Watanabe (1970) estimated that the growth from 1.5 cm TL to 5.0 cm TL is 1.004 mm per day. Off the south of Brazil, chub mackerel grow 7 cm during their first two months of life, and 5.5 cm during the following two months (Seckendorff & Zavala-Camin, 1985). This partially corroborates the data of Kramer (1969), who observed that tank-reared chub mackerel reached between 3.5 and 7.7 cm during their first two months of life. Watanabe (1970) reported a growth rate of 6.6 cm over the first 70 days of life in the Sea of Japan.

In its first year of life, this species increases most in length, at a rate of between 35.4 and 62.59% of the maximum length of the species in each area (Alagarswami *et al.*, 1969; Gagliardi & Cousseau, 1968; 1970; Knaggs & Parrish, 1973; Castello & Cousseau, 1976; Baird, 1977; Angelescu, 1979; Westhaus-Ekau & Ekau, 1982; Pizarro de Rodríguez, 1983; Martins *et al.*, 1983; Martins & Serrano-Gordo, 1984; Mendo, 1984; Aguayo & Steffens, 1986; Zhenbin *et al.*, 1991; Lorenzo, 1992; Perrotta, 1992) (Table 6). Habashi & Wojciechowski (1973) reported that the growth rate is nearly the same in the first 3 years of life, decreasing after the third year. There is clear evidence that the growth rate decreases with age (Angelescu, 1979; Pizarro de Rodríguez, 1983).

In the Gulf of Cádiz (Spain), Rodríguez-Roda (1982) observed that during the colder months, the growth rate is slower, with a condition factor of 0.943, while during the warmer months, the growth rate is higher, with a condition factor of 1.064. This was also observed by Baird (1977), Ouchi (1978), Seckendorff & Zavala-Camín (1985), Dawson (1986), Aguayo & Steffens (1986), Forciniti & Perrotta (1988) and Gluyas-Millán & Uraga (1990) in the waters of South Africa, Japan, Brazil, Ecuador, Chile, Argentina and Mexico, respectively. These authors proved that the formation of growth bands on the otoliths (Fig. 8) is related to feeding intensity and temperature, amongst many other factors. In the case of the Canary Islands, the formation of each growth ring (fast or slow) occurred in the same months every year. This suggests that the factors influencing the formation of growth rings have a seasonal rhythm (Lorenzo, 1992).

In studies of growth of ***Scomber japonicus*** carried out in different areas, the method most frequently used has been interpretation of otolith rings (Table 6). One hyaline zone and one opaque zone constitute one year of life (Dawson, 1986). In the Pacific Ocean, Knaggs & Parrish (1973), Pizarro de Rodríguez (1983) and Dawson (1986), and Kotlyar & Abramov (1983) and Mendo (1984) used this methodology to estimate the growth parameters of chub mackerel populations of California, Ecuador and Peru, respectively. Most authors who have studied the age and growth of this species in the Atlantic Ocean have also used otoliths (Fig. 8). Examples are the work of Castello & Cousseau (1976) in the waters of Argentina, Baird (1977) and Morales & Sánchez (1980) in the southeast Atlantic, and Martins & Serrano Gordo (1984) in Northwest Africa.

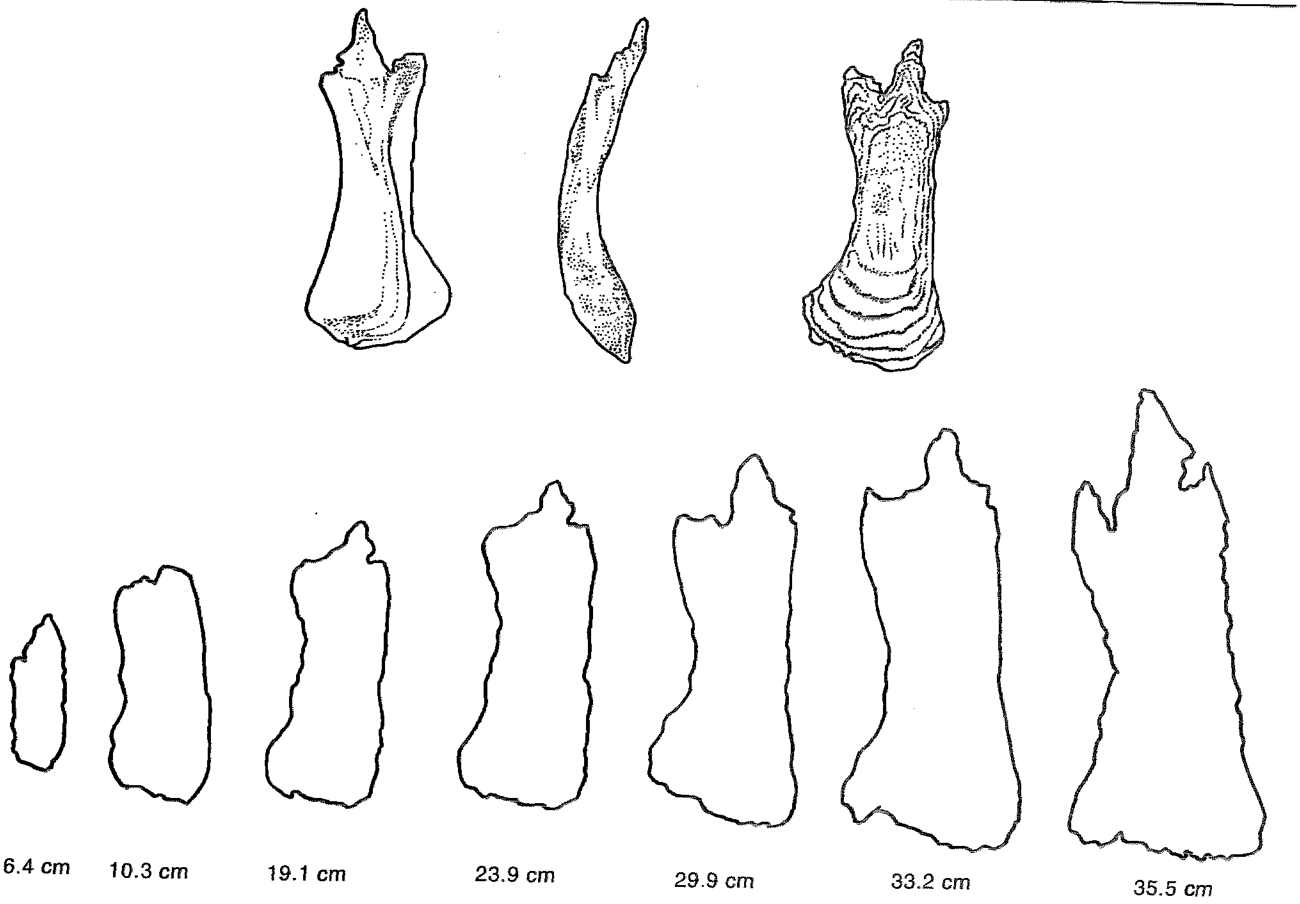


Figure 8. Otoliths of *Scomber japonicus* and their morphological changes with length

In the Atlantic, the growth of chub mackerel has been studied by Martins *et al.* (1983), Staicu & Maxim (1974), Belvèze (1986), Lorenzo (1992), Seckendorff & Zavala-Camin (1985), Perrotta & Forciniti (1994), amongst many others (Table 7). In the Pacific Ocean, this was studied by Fry (1936b), Fitch (1951), Kramer (1969), Knaggs & Parrish (1973), Kotlyar & Abramov (1983), Pizarro de Rodriguez (1983), Mendo (1984), Aguayo & Steffens (1986), Aikawa (1937), Ouchi (1954, 1978), Hatanaka *et al.* (1957), Kondo (1966), Iizuka (1967), Alagarswami *et al.* (1969), Ann (1971) and Belyaev & Ryabov (1987), amongst many others (Table 7).

The length-weight relationship of ***Scomber japonicus*** has also been studied in various areas (Table 7). Perrotta (1988c), Forciniti & Perrotta (1988) and Perrotta (1992) found no statistical differences between the slopes of the length-weight regression lines of males and females. However, Angelescu (1979) detected that males were slightly heavier than females (the slopes of the length-weight regression were 3.4203 and 3.3558, respectively), possibly due to the heavier gonads in males. During the first and second year of life, fish grow faster in length than weight, but after the first spawning, the growth rate in length is somewhat lower than in weight, and therefore adults look robust, like a torpedo (Angelescu, 1979; Lorenzo, 1992).

Lorenzo (1992), off the Canary Islands, found that chub mackerel undergo ontogenetic changes in body-shape, characterized by three well-differentiated stages (Table 1) marked by two significant discontinuities in relative growth. The first stanza, occurs until reach around 14 to 15 cm TL, and consists of negative allometric growth in the form of an intense relative development of the cephalic region. This was also observed by Sánchez (1982), Perrotta & Aubone (1991) and Perrotta (1993) in the Mar del Plata (Argentina), although for a different size interval. Sánchez (1982) pointed out that the gill rakers are formed during this first stanza, when the head reaches 2.7 cm in length, and the fish is approximately 13 cm TL. The second stanza occurs between 14 to 15 and 27 to 28 cm TL, and a proportional decrease in the growth rate of the head relative to the body is observed. After this size, in the third growth stanza, the most prominent feature is a considerable increase in volume. This means that the fish have reached adulthood and therefore, will continue to grow according to an isometric model. The nature of these variations is not very clear specially when comparing their occurrence in different meristics. However, it is possible that these variations are due to ecological and/or sexual processes embedded in the genetic developmental pattern of the fish. The first of these processes could be a change of habitat and diet (Sánchez, 1982; Castro & Lorenzo, 1991;

Table 7. Growth parameters of *Scomber japonicus* by geographic area

LOCALITY	L_∞	K	t_0	θ	b	a	REFERENCE
Sea of Marmara	33.0	0.473		2.71			Pauly, 1978
Greece					2.97	0.031	Petrakis & Stergiou, 1995
Egypt	27.9	0.485		2.58	3.17	0.00567	Rafail, 1972a, b
Libya					3.2229	2x10^{-6}	Gasim *et al.*, 1992
France					3.24	0.00365	Dorel, 1985
Spain					3.3004	2x10^{-6}	Rodríguez-Roda, 1982
Portugal	53.833	0.1735	-2.026	2.70	3.3907	0.00183	Martins *et al.*, 1983
Portugal	51.228	0.2048	-1.5608	2.72	3.5275	0.001099	Martins & Serrano-Gordo, 1984
Portugal					3.23	0.00346	Gonçalves *et al.*, 1997
Azores Island	44.737	0.2447	-1.00	2.69			Westhaus-Ekau & Ekau, 1982
NW Africa	55.375	0.118	-3.178	2.56	3.567	0.00193	Staicu & Maxim, 1974
Morocco	44.1	0.326		2.80			FAO, 1979
Morocco					3.30	0.00407	Belvèze, 1986
Canary Islands	49.2	0.21	-1.40	2.71	3.2592	0.00347	Lorenzo, 1992
Mauritania	55.4	0.118		2.56			FAO,1979
Mauritania-Senegal	44.096	0.309	-1.011	2.78	3.352	3x10^{-6}	FAO, 1986
Mauritania-Senegal	55.36	0.118	-3.178	2.56	3.5676	0.0019	FAO, 1986
Mauritania-Senegal	48.743	0.201	-2.963	2.68			FAO, 986
Mauritania-Senegal	47.7	0.020	-1.688	2.66	3.5505	0.00206	Maxim, 1990
Senegal					3.278	0.00049	FAO, 1986
Cape Verde					2.88	0.0196	Magnusson & Magnusson, 1987
Namibia	88.75	0.04	-12.21	2.49			Morales-Nin & Sánchez, 1980
Namibia	71.60	0.16	1.89	2.91	3.116	0.0060	Ostapenko, 1988
South Africa	68.01	0.207	-0.984	2.96	3.3112	0.0049	Baird, 1977
South Africa	68.0	0.207		2.98	3.31	0.0049	van der Elst & Adkin, 1991
SE Atlantic	62.6	0.39	-0.28	3.18			ICSEAF, 1973
SE Atlantic	41.8	1.17	0.6	3.31			Draganik, 1975
Venezuela	31.6	0.54		2.73			Mendoza, 1993
Brazil					3.0613	0.0779	Seckendorff & Zavala-Camin, 1985
Argentina	48.92	0.1266	-6.2612	2.48			Gagliardi & Cousseau, 1970
Argentina	44.60	0.257	-2.59	2.71	3.18	0.51x10^{-3}	Castello & Cousseau, 1976
Argentina	46.90				3.1888	3.13x10^{-6}	Angelescu, 1979
Argentina					3.2199	2.64x10^{-3}	Sánchez, 1982
Argentina	41.3/43.8	0.42/0.34	-1.07/-0.13	2.85/2.81	3.27/2.95	1.9x10^{-6}/1.2x10^{-5}	Perrotta, 1988c
Argentina	46.01	0.28	-1.5421	2.77	3.40	8.89x10^{-7}	Perrotta, 1992
Argentina (M del Plata)	41.73	0.35	-1.7073	2.78	3.0686	6.52x10^{-6}	Perrotta & Forciniti, 1994
Argentina (El Rncón)	42.31	0.27	-2.5668	2.68	3.6772	1.64x10^{-7}	Perrotta & Forciniti, 1994
USA (California)	40.0	0.4		2.90			Beverton & Holt, 1959
USA (California)	40.0	0.4		2.90			Beverton & Holt, 1959
USA (California)	43.612	0.2444	-3.0222	2.65	3.3936	0.00137	Knaggs & Parrish, 1973

Table 7. (continued)

LOCALITY	L_∞	K	t_0	θ	b	a	REFERENCE
USA (California)	40.5	0.4		2.56			Parrish & MacCall, 1978
USA (California)	42.3	0.25		2.65			Erzini, 1991
Mexico (Pacific)	29.3	0.50	-0.17	2.63			Cisneros *et al.*, 1990
Mexico (Pacific)	29.8	0.61	-0.27	2.73	3.2	$1.72x10^{-5}$	Nevárez-Martínez *et al.*, 1994
Ecuador	39.21	0.2294	-1.7880	2.55	3.0005	$1x10^{-6}$	Pizarro de Rodríguez, 1983
Ecuador	40.50	0.214	-2.07	2.54			Dawdson, 1986
Ecuador	37.40	0.466		2.81			Morales, Nin, 1988
Peru					3.65	0.00126	Jordán, 1979
Peru					3.57	0.00194	Kotlyar & Abramov, 1983
Peru	40.6	0.4086	-0.0488	2.83	5.32	$8.378x10^{-8}$	Mendo, 1984
Peru	40.6	0.409	-0.04	2.82			Dawson, 1986
Chile					3.46	0.0027	C.F.P., 1980
Chile	44.62	0.16	-1.553	2.50			Serra, 1983
Chile	44.37	0.1640	-1.5427	2.50	3.4230	0.00029	Aguayo & Steffens, 1986
Chile	44.6	0.162	-1.55	2.51			Dawson, 1986
Russia (Pacific)	60.0	0.306		30.42			Pauly, 1978
Japan					3.1657	0.00079	Hatanaka *et al.*, 1957
Japan	41.26	0.26	-1.69	2.65			Alagarswami *et al.*, 1969
Japan	40.18	0.408	-0.718	2.82	3.342	$1.75x10^{-5}$	Ann, 1971
Japan	41.6	0.49		2.928			Kurogane, 1974
Japan	38.05	0.63	-0.98	2.96			Ouchi, 1978
Japan	44.0	0.441		2.931			Pauly, 1978
Japan	38.1	0.63		2.961			Erzini, 1991
Taiwan	40.279	0.265	-1.7671	2.63	3.31307	$0.583x10^{-5}$	Zhenbin *et al.*, 1991
Yemen (G. Aden)	53.0	0.28		2.90			Edwards & Shaher, 1991

Castro, 1993; Castro & Hernández-García, 1995). On the other hand, Lorenzo (1992) pointed out that the fish, upon reaching sexual maturity, chub mackerel undergo a series of changes in the shape of discontinuities in their relative growth. Angelescu (1979) shows that during the first two years of life, there is greater growth in length than in width, the rhythm of growth changes from the first sexual cycle (second year of life) onwards, and the vertical and transverse axes of the adult body preponderate.

3.4.4 Metabolism

Chub mackerel are ectothermic fish, i.e. they lack physiological mechanisms to regulate body temperature (Roberts & Graham, 1979). However, they have two major adaptations to avoid potentially damaging temperatures and to survive in a dynamic, heterothermal environment: they are physiologically tolerant to temperature (6 to 29°C) (Schaefer, 1986) and are able to thermo-regulate through behaviour, thanks to their acute temperature sensitivity (Bull, 1952) coupled with their swimming capabilities.

Roberts & Graham (1979) reported a mean heart rate of 106 beats per minute in chub mackerel cruising at 1 to 1.5 l/s (lengths per second) in the laboratory. When the fish accelerated to 4 to 5 l/s, the mean heart rate was 130 beats per minute but returned to the resting rate within a few minutes after deceleration. They also found that chub mackerel do not develop large temperature excesses in their tissues when swimming at basal (1.3 to 1.9 l/s) or sustainable speeds (3 to 5 l/s). The temperature excesses, measured in the heart and the red and white muscles, never exceeded 1°C. These authors reported further that in fast-swimming scombrids both the red and white muscles function in low-speed swimming and that both probably remain active throughout a wide range of sustainable speeds, as well as at burst velocities.

Klawe *et al.* (1963; quoted by Schaefer, 1980) and Kakuno *et al.* (1994) determined that the haematocrit values and haemoglobin contents of the chub mackerel blood were found to be high (haematocrit 63%, haemoglobin 8.0 to 14.8 g/100 ml for fish measuring

24.4 to 28.7 cm). They noted that in fish, the haemoglobin is generally associated with the level of activity of the species. The level of haemoglobin concentration in chub mackerel was the lowest of the six species of scombroid fish examined by Klawe *et al.* (1963; quoted by Schaefer, 1980). Values of erythrocytes counts, haematocrites, haemoglobin and mean corpuscular haemoglobin concentration were positively correlated with dark muscle content, which seems to be related to the level of activity of the species (Kakuno *et al.* 1994).

Obatake & Kawano (1988) reported that the mean value of dark muscle ratio was 11.0 ± 1.4. The dark muscle to whole muscle ratio increased by 0.69% per 100 g body weight and by 0.24% per 1 cm body length.

Seno (1972) and Bykov (1983) give the chemical composition of chub mackerel according to the form of preservation (fresh, salted, dried sticks and canned in brine) (Table 8). One gram of chub mackerel was on average 1.19 Kcal (Hatanaka & Takahashi, 1956).

3.5 Behaviour

3.5.1 Migration and local movements

Watanabe (1970) observed that a primitive hint of migration seems to exist in young 5.0 to 18.0 cm TL. Novikov (1986) reports that long-distance migrations of chub mackerel during the annual biological cycles are governed by oceanographic conditions, intraspecific population structure and abundance dynamics.

In the northeast Atlantic, chub mackerel arrive each summer to the coast of the Gulf of Biscay, probably from the coast of Portugal, and remain there until the beginning of winter (Lucio-Gallo, 1992). Along northwest Africa, adult mackerel undertake considerable seasonal migrations (Fig. 9). Razniewski (1967) and Domanevsky (1970) observed that after hatching and during the first year of life, young mackerel are found in open waters beyond the shelf. In summer, during their second year of life, immature fish migrate into the shelf and are found most abundantly in the area of 28 to 24°N. They remain there from autumn to the following spring, often in the same areas where mature individuals occur. In spring, they migrate to the open ocean and shoals are seldom found on the shelf. Off Mauritania, fish migrate from Cape Blanc to Cape Vert at the beginning of winter, and take the opposite route during late spring (Garcia, 1986; FAO, 1986). According to FAO (1986), off Mauritania, 1 to 2 year old fish are found north of 23°N, and 2 to 4 years old fish occur between 22 and 23°N. Older fish are normally found south of those areas. Domanevsky (1970), Pârcalaboiu (1971) and Habashi & Wojciechowski (1973) reported that ***Scomber japonicus*** also performs diurnal migrations, which influence the catches. They keep close to the bottom during daytime, and rise to the upper layers in the twilight. Generally, smaller fish were caught deeper than the larger fish. These authors pointed out that chub mackerel spawn during winter in the inshore grounds, and migrate toward the open sea feeding areas after spawning.

Chub mackerel are most abundant in the northern Benguela Current region during the austral spring and summer, appear to migrate through the central region in autumn, and are caught on the southern fishing grounds from winter to mid-spring. These movements might be related to seasonal patterns of prey availability (Crawford & De Villiers, 1984; Wysokinski, 1986). Baird (1975; 1978a) described an offshore to inshore migration of adult chub mackerel during the winter months. He related this to

Table 8. Chemical composition of *Scomber japonicus* according to preservation method (fresh, salted, dried sticks, and canned in brine)
(Seno, 1970; Bykov, 1983)

	Calories	Moisture (g)	Raw proteins (g)	Raw fats (g)	Sugar (g)	Ashes (g)	Calcium (mg)	Phosphates (mg)	Iron (mg)	Vitamins (mg)					Rate of abandon
										A (IU)	B1	B2	C	Niacin	
Fresh	111	76.0	18.0	4.0	0.7	1.3	5.0	190.0	1.8	50.0	0.15	0.20	3.0	8.0	46
Salted	142	65.0	25.2	4.2	0.9	4.7	25.0	240.0	7.0	0.0	0.03	0.05	0.0	10.0	25
Dried	366	14.1	74.0	7.4	0.8	3.7	17.0	650.0	7.0	0.0	0.03	0.05	0.0	-	0
Brine	190	65.7	17.4	13.4	0.0	3.5	290.0	260.0	1.6	0.0	0.02	0.10	0.0	-	0

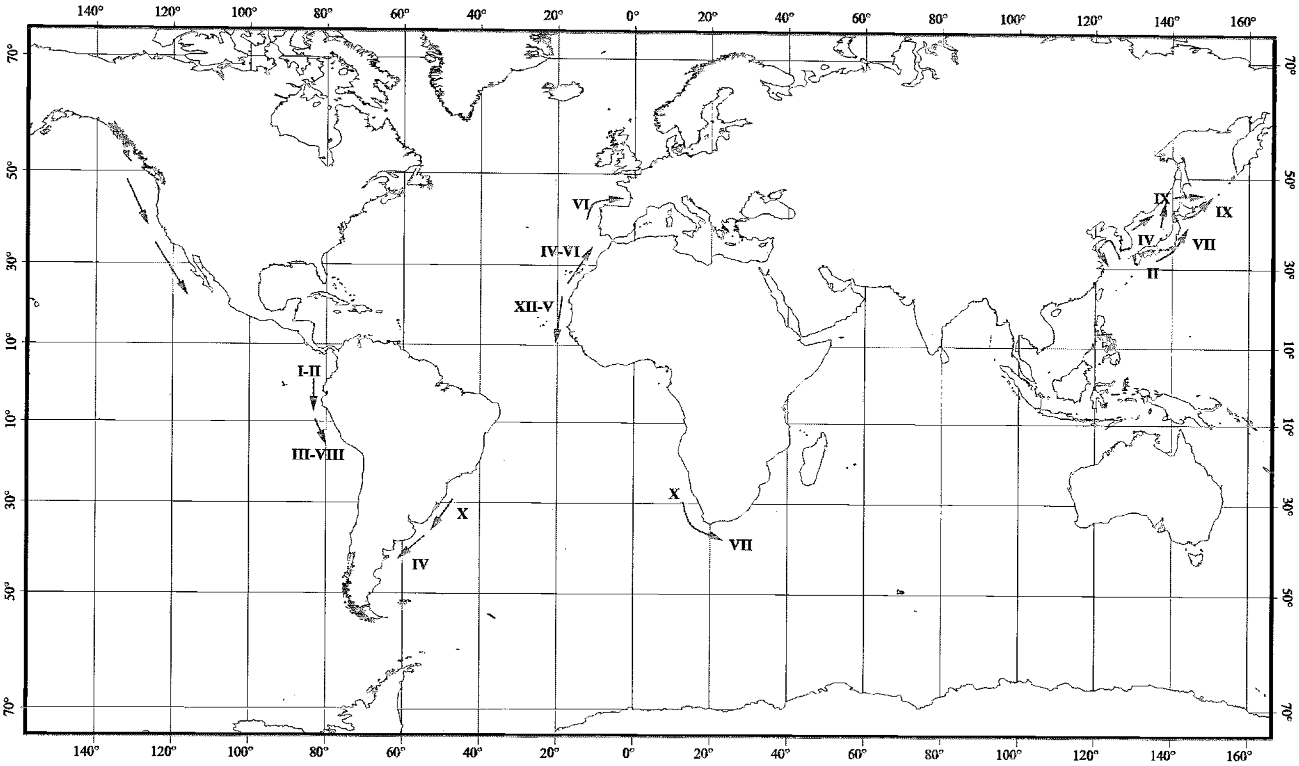


Figure 9. Schematic migratory paths and local movements of *Scomber japonicus*. (Roman numerals indicate the starting and finishing months of migration.)

spawning and to an onshore current set in motion by northwesterly winds that bring relative warm water (14 to 15°C) closer to the coast. This migration generally takes place in the vicinity of Cape Columbine, chub mackerel often moving later in a southerly direction as far as Dassen Island (Baird, 1974; Crawford, 1983) (Fig. 9). It is worth noting that in July, the distribution tends to be offshore, centring at the 200 m bottom contour outside Dassen Island (Crawford, 1981a). Baird (1978a, b) observed that chub mackerels tend to assume a greater offshore distribution as they grow older, probably because of the progressive change in their diet. According to Baird (1975) the hydro-ecology of the large chub mackerel is characterized by a temperature range between 14.0 and 15.2°C, a salinity range between 35.1 and 35.4‰, and a typical content of dissolved oxygen of 6 ml/l.

Perrotta (1992) concluded that the smaller fish that make up the stock of the north Patagonian region (Argentina Sea) occur as a result of the southward movement of fish coming from offshore areas beyond the La Plata River (Fig. 9). These are juveniles that will recruit to the adult stock. Castello & Cousseau (1976) and Angelescu (1979) reported that chub mackerel show up in waters next to the Mar del Plata around October and November, remaining there until March-April approximately. They approach the coastal area in size-segregated schools, with the adults arriving first and juveniles arriving at the end of the season. After spawning, the schools move progressively back from the coastal fishing area toward the northeast and to the slope of the continental shelf (Angelescu, 1979). Angelescu (1979) observed that schools of adults were located between a depth of 6 and 8 m during the first hours after dawn, descending close to the thermocline (10 to 20 m in summer), during the hours of brightest light.

Fry & Roedel (1949) and Roedel (1949b; quoted by Schaefer, 1980) report on a tagging programme carried out from July 1935 to March 1943, during which 76 038 chub mackerel were tagged from Magdalena Bay (Baja California), to Tillamook Head (Oregon). The fish were found to migrate throughout the region, individuals from as far north as Oregon and as far south as central Baja California migrating to the southern California area (Fig. 9). No fish tagged south of San Roque Bay, Baja California, were recaptured, indicating that probably these do not migrate to the waters off southern California or contribute to that fishery. The California Department of Fish and Game (1994) reported that the ENSO (El Niño Southern Oscillation) conditions caused extensive movements of chub mackerel to the north and out of the area covered by CalCOFI and fish spotter surveys.

During January and February, chub mackerel are found in the northern part of Guayaquil Gulf (Ecuador). From March to July, they migrate toward the south and in August, they are found in Salinas (French & Menz, 1983) (Fig. 9). Off Chile, Böhm *et al.* (1984) reported that chub mackerel occur from the surface down to a depth of 60 m and make diurnal migrations. This species has a preference for temperatures and salinities of 15 to 23°C and 34.80 to 35.25‰, respectively (Castillo-Valderrama, 1995).

Around Japan, the migrations and local movements of chub mackerel are reported by Kawakami (1962), Kojima (1962), Usami (1976), Usami & Matsushita (1974), all quoted by Schaefer (1980), Watanabe (1970), Usami (1973), Tanaka (1983) and Limbong *et al.* (1991) (Fig. 9). The Pacific stock of chub mackerel inhabits the coastal waters inside Kuroshio and spawn in the waters around the Izu Islands in the Pacific off central Honshu. Watanabe (1970), Belyaev & Rygalov (1986) and Limbong *et al.* (1991) reported that during winter and spring adults aggregate off the Boso Peninsula to around the Izu-Shoto Islands. Spawned eggs and larvae are transported by the Kuroshio current and extend their distribution eastward and northward. The earliest-staged mackerel are trans-located to a location that defines the future habitat of the fish. Juveniles that migrate to coastal waters, grow in the coastal region and gradually disperse northward within this region. While the majority of the population that drifted into the mixing water area off the Tohoku region may stay there and grow in an offshore area (Watanabe, 1970), juvenile fish come back and congregate in waters off the central Honshu and winter there (Tanaka, 1983). An offshore-inshore migration of juvenile and young fish occurs in summer with the shoreward shift of a warm-water mass toward the Sanriku coast. Also, the immature fish migrate toward the Joban-Kashimanada with falling water temperatures in autumn and winter (Watanabe, 1970; Belyaev & Rygalov, 1986; Limbong *et al.*, 1991). One-year-old fish extend their distribution as far north as northern Honshu in summer and return to waters adjacent to central Honshu in winter. During April, in their third year of life, young fish join the adult fish stock after the spawn, and migrate as far north as Hokkaido and the central and southern Kurile Islands (some years the fish appear around 49°N and 172°E). There, they form stable feeding concentrations around the 20 to 30 m thermocline (Watanabe, 1970; Tanaka, 1983; Belyaev, 1985a; Stovbun, 1992). In the southern Kurile area, chub mackerel do not migrate beyond 170°E to feed, although individual schools are sometimes observed in more eastward areas (Belyaev, 1980a). Belyaev (1985a) reported that this species performs diurnal vertical migrations within a 100 m layer during wintering. They move to the waters off northern Honshu when autumn comes, and begin to migrate southward along the coast through a system of long-range eddies and gyres to return to the wintering area (Watanabe, 1970; Tanaka, 1983; Belyaev, 1985a). These fish spawn for the first time at age 3 around the Izu Islands (Watanabe, 1970; Tanaka, 1983). Tagging experiments conducted between 1950 and 1968 on the Japanese Pacific subpopulation of chub mackerel and reported by Usami & Matsushita (1974; quoted by Schaefer, 1980), substantiate the Pacific coast migrations described by Watanabe (1970). Usami (1973) observed an aggregation of the chub mackerel upon the insular shelf and banks along the 200 m isobath mainly in the coastal waters inside the Kuroshio Current. The water temperature at the 50 m layer, which was the most frequent habitat of shoals, was about 15 to 20°C. D'yakov *et al.* (1984) observed that chub mackerel were recorded in relatively warm and cold waters during northward and southward migrations, respectively.

Makoto (1957) and Hasegawa *et al.* (1991a) demonstrated through tagging experiments that some chub mackerel from the Sea of Japan enter into the Pacific Ocean through the Sangaru (Tsugaru) Strait. Recapture data for fish tagged near the Oki Islands during May and June indicated that fish in the western Sea of Japan migrate as far north as Point Saruyams on the Noto Peninsula (Kojima, 1962; quoted by Schaefer, 1980). Usami (1976; quoted by Schaefer, 1980), reported that in the Sea of Japan, chub mackerel migrate to the west coast of Hokkaido, Soya Strait and the Sea of Okhotsk. Kawakami (1962), also quoted by Schaefer (1980), reported that in the summer, chub mackerel in Ishikari Bay aggregate into subschools which tend to enter the fishing grounds at intervals of about 7 days, which corresponds to the period between the waxing and waning of the moon. Off Korea, and under the influence of environmental conditions, chub mackerel begin the spawning migration northward in spring (April-June), disperse or move again northward in the summer (July-September) and come back south in the autumn (October-December) (Park, 1977; Wu, 1987). Wu (1987) also reports that one branch of the spawning population migrates through the northern part of the Huanghai Sea and enters the Bohai Sea, while the other approaches the offshore area near Qingdao (China). Schools concentrate between a depth of 20 and 30 m at temperatures around 20°C; the depth range is greater in places where there is no thermorcline (Gong *et al.*, 1972; Imai, 1967).

3.5.2 Schooling

Croker (1933) reported chub mackerel to be gregarious, running in schools, and yielding catches of 50 short tons or more in a single purse-seine set. Watanabe (1970) reported that chub mackerel larvae begin schooling at approximately 30 mm. Van Olst & Hunter (1970) investigated the schooling organization of chub mackerel from the larval through adult stages. Adult chub mackerel schools were the most compact and organized. School organization was unaffected by food deprivation for 9 days in the laboratory.

Parr (1927) and Shlaifer (1942) found that when chub mackerel were blinded they did not school. Neproshin (1979) observed that before 0800 hours, when twilight illumination and low temperatures occur, chub mackerel aggregations are in a straggly state and schooling behaviour is absent in the fish. With the start of the day, when illumination has increased considerably, the fish form schools. Neproshin (1979) also observed that after 1800 to

1900 hours, with the decrease in illumination, dispersal of the aggregation occurs again.

Hasegawa & Soeda (1985) studied the mechanism of schooling behaviour of chub mackerel. Their findings are summarized below.

1) All individuals in the school interact with each other so that swimming speed fluctuates with time.

2) Each individual maintains the same orientation and a constant distance from each other (van Olst & Hunter (1970) and Aoki *et al.* (1986) reported that the mean distance to the nearest neighbour was between 0.1 and 1.51 body lengths and that the separation angle was 85°).

3) Orderly movement of the school occurs when the swimming speed of each fish remains constant; the concentration of the school results in the disruption of such behaviour.

4) When the school turns, each individual regulates its swimming speed according to its position in the school. Chub mackerel form schools according to individual size (Razniewski, 1967). The size range within schools is L(range)=±0.4L (L=mean body length) (Inoue, 1978).

Chub mackerel can be found in unmixed schools or mixed with ***Trachurus symmetricus*** and ***Sardinops sagax caeruleus*** (Parrish & MacCall, 1978; Schaefer, 1980). Off the Canary Islands, Castro (1991) reported that juveniles form mixed shoals with ***Sardina pilchardus***, ***Boops boops*** and ***Atherina presbyter*** of similar size. Vedenskii (1954, quoted by Radakov, 1973) observed that schools of chub mackerel in the Sea of Japan are generally variables in size and may include up to 50 000 to 100 000 specimens.

3.5.3 Swimming behaviour

Hunter & Kimbrell (1980) investigated the swimming behaviour, including cruising speeds, for laboratory-reared larvae and juveniles. They reported that larvae of 3 to 5 mm SL, have a high tail beat frequency of about 30 beats/sec and a low tail beat amplitude of 0.16 SL. Cruising speeds of chub mackerel increased markedly over the larval period from 0.46 cm/sec (1.3 SL/sec) for first-feeding larvae (3.6 mm SL) to 5.6 cm/sec (3.8 SL/sec) for fish at metamorphosis. Finfold larvae of 5 mm SL and smaller, swim by strong tail beat propulsion and feed with the mouth widely open (Kohno *et al.*, 1984).

In adult fish, speed relative to size decreases with size (Weeb, 1975). Hunter & Zweifel (1971) reported that the equation describing swimming speed-tail beat frequency of adult chub mackerel is $V=-2.20TL^{2/3} + 0.82TL*F$, where V is the swimming speed in centimetres per second, F is the tail-beat frequency in beats per second, and TL is the total length in centimetres.

The swimming speed of ***Scomber japonicus*** is dependent on water temperature. Swimming speed is 1.19 lengths per second at 12 to 13°C, and 1.16 lengths per second at 16 to 17°C. A significant difference was detected in the mean swimming speeds in the cooled (7 to 11°C; 0.708 to 0.917 lengths per second) and heater (24 to 29°C; 1.208 to 1.458 lengths per second) treatment tanks (Schaefer, 1986). Magnuson (1973) reported a basal swimming speed of 1.5 lengths per second. This low swimming speed is sufficient to maintain hydrostatic equilibrium in the chub mackerel due to its low density and the presence of a gas bladder. According to van Olst & Hunter (1970), during steady swimming at nearly all velocities, tail beat amplitude is a constant proportion of the body (0.221 body length). These authors reported that when chub mackerel accelerate, they perform a few very high amplitude beats (0.4 to 0.5 body lengths) and then gradually decrease amplitude to the steady swimming level. Sambilay (1990) reported a burst swimming speed of 8.35 SL/s (2.254 m/s) for a fish of 27 cm SL.

3.5.4 Responses to stimuli

Chub mackerel are known to be attracted to light, as they have been sampled at night off Baja California using a blanket net (Radovich & Gibbs, 1954; quoted by Schaefer, 1980). Japanese fishermen capture sizeable quantities of chub mackerel fishing with light. The attraction of chub mackerel to artificial lights is probably more due to feeding instinct than to phototaxis (Castro, 1995). Small schools move in and out of the illuminated area and sometimes show negative phototaxis, especially the larger individuals (Castro, 1991). The importance of feeding in the vicinity of artificial light has been proven by the effective Japanese fishing method using both light and chum simultaneously (Ben-Yami, 1976; quoted by Schaefer, 1980). Inoue *et al.* (1984) reported that under dark conditions, chub mackerel showed a weak upstream movement. Hasegawa *et al.* (1991b) analysed the retinal adaptation in chub mackerel attracted to fishing lamps. Chub mackerel were mostly hooked at a light intensity ranging from 10^{-1} to 10^{-3} lx, and were hooked more frequently in darker areas after midnight than before midnight. The maximum sensitivity is reached at 492.5 nm (Munz, 1964). The correlation between cone migration and pigment migration was high before midnight but was low after midnight.

Chub mackerel react sharply to fishing gear and vessel noise by attempting to escape from noisy areas (Neproshin, 1979; Kujorenko, 1986). The maximum sound sensitivity was in the range of 500-1400 Hz (Sorokin, 1987a). Sorokin (1987a; b) reported that the acoustic canal plays a minor role in the orientation behaviour of this species. Khudenko *et al.* (1983) observed that chub mackerel were sensitive to dolphin sounds.

The palate receptors of ***Scomber japonicus*** were sensitive to individual amino acids at a concentration of 10^{-2} M, and they were responsive to nucleotides at 10^{-4} M. Chub mackerel are highly sensitive to leucine, with a threshold of around 10^{-6}-10^{-5} M (Ishida & Hidaka (1987).

Perrotta (1988a) reported that when schools are being caught with a purse seine, fish try to move out of the enclosure following the current, guided by an individual which acts as a vertex of a wedge constituted by the subsequent fish.

3.5.5 Temperature range

According to Schaefer (1986), chub mackerels are eurythermal, with lower and upper temperatures ranging from 5 to 30°C, when subjected to a progressive temperature change of 1°C per day. This author reported that chub mackerel continue to feed until temperatures were within 4 to 2°C of the average lower and upper lethal temperature. The lowest and highest non-stressful temperatures for ***Scomber japonicus*** are estimated to be between 10 and 12°C and between 23 and 27°C, respectively. These are the temperatures at which significant changes in activity (both feeding and swimming) occurred (Schaefer, 1986).

4. POPULATION

4.1 Structure

4.1.1 Sex ratio

Atli (1960) found that in the Sea of Marmara and in the south of the Black Sea, 50.7% of fish sampled were females and 47.6% were males. Mužinic (1981) found that in the Adriatic Sea, males and females were almost equally represented in his samples. Giama *et al.* (1987) in waters of Lybia, found that the sex ratio was 1:1, although there were variations between seasons.

Lorenzo (1992) recorded that off the Canary Islands, the proportion of sexes changes annually with no significant prevalence of females. Along the African coast, between Cape Jubi (Western Sahara) and Cape Vert (Mauritania), Staicu & Maxim (1974) found a slight deviation in the sex ratio in favor of females, although this approached 1:1 during winter. Off South Africa, Baird (1978 a) found that the sex ratio was close to 1:1 with a slight predominance of females most years with the exception of 1972. The predominance of one sex over the other varies between size classes: females were consistently more common than males, predominating 13.5% between the lengths of 46 cm and 55 cm.

In waters south of Brazil, Seckendorff & Zavala-Camín (1985) observed that the sex ratio was 1:0.94, with a slight predominance of males from October to March, and with prevalence of females from April to June.

In the eastern Central Pacific, Kramer (1969) found that the sex ratio was 1:1. Watanabe (1970) and Usami (1973) found similar results in the Sea of Japan. However, the mean ratio of females by maturity stages was lower during the initial spawning period and became higher in prespawning period (Usami, 1973). Off Peru, the sex ratio was 1:1 for fish under 36 cm, but females predominated for sizes 37 to 40 cm (Mendo, 1984).

4.1.2 Age composition

Domanevsky (1970) reported that in the northwest Africa, during the fishing season 1963-1964, 4-year-old mackerel predominated in the catches. Two-year-old individuals represented about 10% of the catch. In 1964-1965, the main part of the catches consisted in 3-year-old fish, and individuals of 4, 5 and 6 years were caught in negligible quantities. Habashi & Wojciechowski (1973) observed that fish of 3 and 4 years old were the most numerous, and the maximum age was 8 years. Maxim *et al.* (1990) reported that in 1988, the age range of chub mackerel caught off Mauritania was between 1 and 10 years old, but 2 and 3-year-old fish were dominant. Despite this, Krivospitchenko (1980) reported that the maximum age he found for fish from the Sahara subarea was 18 years although the mean was 8.8 years (Table 6).

During the period 1964-1976, South African chub mackerel landed by purse seines ranged in age from 0 to 8 years old, but 0 to 4-year-old fish were dominant (Crawford, 1981b). Ostapenko (1988) observed that catches were made up of fish from 1 to 11 years old, with the dominant age classes from 3 to 8 years old (Table 6).

Off the Mar del Plata (Argentina), the exploited population was made up almost exclusively of adults with a maximum age of 12 years (Perrotta & Pertierra, 1993) (Table 6). The first fully-recruited age-class during the 1969-1972 fishing season was 2 years old, but this was 1-year-old between 1973 and 1975. From 1974 onward, the disappearance of individuals over 3 years old was accentuated and some irregularities were observed during the fishing seasons of 1971-1972 and 1973-1974, when 3 to 7 and 3 to 6-year-old fish were caught, respectively (Castello & Cousseau, 1976). Between 1981 and 1990, the mean age in the catches fluctuated between 3.29 and 4.74 years, while the mean age of the population varied between 1.92 and 2.49 years (Perrotta & Pertierra, 1993).

Several authors have published information on the age composition of chub mackerel in the California commercial landings since 1939. Fitch (1952; 1953) reported that the oldest chub mackerel was 12 years old. Fitch (1956) reported that fish over 8 years old were rare and 6-year olds were becoming very uncommon. Kramer (1969) noted that most of the fish taken commercially were less than 6 years old.

Parrish & MacCall (1978) estimated the catch by age groups for the 1929-1930 to 1969-1970 seasons. Gluyas-Millán & Muñoz-Gómez (1993) reported that off Vizcaino Bay (Mexico), the age range in the catch was between 1 and 8 years old, and 4-year-old fish represented over 70.5% of the total catch (Table 6).

The catches off Peru consist of 10+ age groups (Schaefer, 1980). However, the maximum age recorded by Kotlyar & Abramov (1983) was 6 years, but considering that fish up to 46 cm long were found in small numbers, the maximum age of fish in this region might be 7 to 9 years. Serra (1983) reported that chub mackerel caught in the North of Chile reach 9 years of age (Table 6).

In Japan, off the Pacific coast of Honshu, most of the adult chub mackerel caught by the fishery are 3 and 11 years of age (Table 6). In 1956-1958, the proportions of 2 and 3-year olds were larger than usual. The catches for 1962-1965 consisted mainly of 3 and 4-year olds, and during 1966-1970 the proportions of older fish were greater than in previous years (Watanabe, 1970). Usami (1976), quoted by Schaefer (1980), reported on the age and size composition of the fish from the various fishing grounds around Japan.

4.1.3 Size composition

From 1921-1924, fish from the Mid-Dalmatian islands area (Adriatic Sea) ranged from 15 to 34 cm TL, and from 14 to 36 cm TL in 1954-1957 (Mužinic, 1979a; b). Giama *et al.* (1987) reported that off Lybia, the size range was between 19.5 and 31.5 cm TL. During 1977-1978, the length-range in the fishery of the Gulf of Cádiz fluctuated between 17 and 28 cm (Rodriguez-Roda, 1982). Off Portugal, Matins & Serrano-Gordo (1984) reported that the size composition was between 21.5 and 49 cm. The length range of chub mackerel caught during the last quarter of 1988 and 1992 by purse seiners in the Basque Country (Spain) was between 28 and 47 cm (Martín, 1989; Lucio-Gallo, 1993).

Habashi & Wojciechowski (1973) reported that the length-range observed off northwest Africa was between 15 and 50 cm TL. The 30-35 cm length class predominated in the catches of 1963-1964, while fish of 27 to 32 cm were most abundant in the 1964-1965 fishing season (Domanevsky, 1970). Habashi & Wojciechowski (1973) report that fish of 38 to 40 cm dominated in the catches of 1969-1972, while in 1973, the class of 25 to 30 cm length was dominant. These authors suggested that these differences may be connected with the fact that in 1973 most of the Polish catches came from the coast of Morocco-Western Sahara, while those between 1969 and 1972 were from the Mauritania-Senegal shelf. Belvèze (1986) reported that between 1975 and 1982, the length range of mackerel caught by purse seiners off Morocco was 9 to 42 cm, and the mean size decreased from 28.1 cm in 1975 to 16.0 cm in 1977, and increased again to 20.9 cm toward 1982. Krivospitchenko (1980) observed that the size range of chub mackerel caught in the Western Sahara subarea was between 16 and 43 cm, with a mean length of 30.26 cm in the winter of 1975-1976, 24.61 cm in the winter of 1976-1977 and 22.07 cm in the winter of 1977-1978. Holzlöhner & Kloxin (1985) recorded mean sizes between 26.1 and 35.2 cm in 1982, and between 31.9 and 33.5 cm in 1983, with larger fish in the first quarter and smaller fish in the third quarter. Maxim *et al.* (1990) reported that in 1988, the length-range of chub mackerel caught off Mauritania was between 16 and 43 cm TL. However, the dominant length classes were in the range of 23 to 28 cm. Viskrebenzev (1963) observed that in the region of Senegal the length-range was larger than recorded in the region of the Gulf of Guinea.

Off South Africa, inshore chub mackerel were predominantly small and medium-sized. Small fish varied in length from 10 to 25 cm, while medium-sized fish ranged from 25 to 45 cm (Baird, 1978a). In 1977, the length distribution ranged from 23 to 59 cm TL. From 1965 to 1975, the average length decreased continuously from 59.5 to 28.1 cm (Dietrich & Ritzhaupt, 1979). The maximum length observed in the catches of 1984 was 70 cm (Ostapenko, 1988).

In the waters of Brazil, Seckendorff & Zavala-Camín (1985) observed that the length-range of chub mackerel varied between 11.1 and 34.5 cm FL. Castello & Cousseau (1976) observed that the size range fluctuated between 21 and 47 cm off Argentina from 1969 to 1975, with the mean length decreasing progressively from 33.7 cm in the 1969-1970 fishing season to 27.8 cm in the 1974-1975 fishing season. There is a tendency to a size increase in chub mackerel from October to November and a predominance of lengths between 31 and 40 cm at the beginning of the fishing season. The monthly size distribution shows two well-marked modes, 23 and 31 cm (Perrotta, 1992). Juveniles are frequent in the catches and the length range was 17 to 45 cm (Cousseau *et al.*, 1987). Angelescu (1979) recorded a range from 6.5 to 45.5 cm TL.

Fitch (1956) reports the largest chub mackerel on record in the California fishery as being nearly 63.5 cm in length and weighing 2.8 kg. Length-frequency distributions of chub mackerel in the commercial fishery of the eastern Central Pacific have not been published, except for the 1929-1930 and 1930-1931 seasons (Parrish & MacCall, 1978), and the 1968-1969 season (Blunt & Parrish, 1969). Dotson & Griffith (1996) noted that chub mackerel ranging from 6 to 45 cm were caught with a high-speed midwater rope trawl. Gluyas-Millán & Muñoz-Gómez (1993) reported that off Vizcaino Bay (Mexico) fish were between 17.6 and 36.3 cm SL. The mean standard length was 23.8-25.3 cm during 1984-1986.

Morales-Nin (1988) found that in Ecuador, the length-range of chub mackerel varied between 11 and 38 cm, although she pointed out that fish under 15 cm were rare in catches. Fish were most common in the range from 20 to 30 cm. Chub mackerel landed in Peru range from 17 to 44 cm in length with an average of 30 cm, and an average weight of 325 g (Jordán, 1979; quoted by Schaefer, 1980). Kotlyar & Abramov (1983) reported that, mackerel caught off Peru in 1972 ranged between 12 and 46 cm in length, and between 21 and 1 200 g in weight. Off Chile, Aguayo & Steffens (1986) found that chub mackerel length varied between 12 and 41 cm FL.

Aikawa (1937) reported a length range from 5 to 50 cm for chub mackerel. Alagarswami *et al.* (1969) found that mackerel collected from Sagami Bay during November 1966 and December 1967, were 12.8 to 40.6 cm FL. Usami (1973) observed that fish caught in the Kanto region averaged 30 to 35 cm FL in the period 1961-1965, and 35 to 40 cm in the period 1966-1969, fluctuating since 1970 (a mixture of small fish, 25 to 30 cm, and larger ones, 40 to 45 cm). Usami (1976; quoted by Schaefer, 1980), reports that chub mackerel 50 cm or more in length and 2 kg in weight have been captured off the Pacific coast of Japan.

4.2 Abundance and density

4.2.1 Average abundance

The abundance of chub mackerel around the Canary Islands was estimated at 38 000 t using an EK 400 SIMRAD echosounder of 38 KHz and a QD digital integrator (Pastor & Delgado de Molina, 1985). The major concentration of chub mackerel was found south and southwest of the eastern islands. Bordes *et al.* (1993) estimated that the biomass of chub mackerel off Gran Canaria was 8 705 t.

Marchal & Boely (1977; quoted by Troadec & Garcia, 1979) estimated the biomass of chub mackerel in 120 000 t from an acoustic survey carried out between October and November 1974 along the shelf between Cape Roxo and Cape Barbas (northwest Africa). This biomass is equivalent to the total catch of mackerel in 1974, and lower than the estimated maximum catch at equilibrium (170 000 t). This difference in the estimates exists because the area studied which was smaller than the total area of distribution of the stock (Troadec & Garcia, 1979).

Estimates of stock size using data since 1968 showed that the chub mackerel population off South Africa was in the order of 200 000 to 300 000 t (Baird, 1975). This estimate corresponds only to the fully recruited proportion of the stock. Baird (1975) estimated that the size of the offshore population was between 115 000 and 180 000 t.

Mendoza (1993) estimated the biomass of chub mackerel off northeastern Venezuela in 24 000 t. Johannesson (1975) and Rijavec & Carvalho-Amaral (1977), used echo-integration to estimate the biomass of neritic pelagic fish in the southeast and south of Brazil, and observed that chub mackerel ranked second in importance behind sardine (***Sardinella brasiliensis***), but they were not able to determine the proportions.

The total biomass estimated for the chub mackerel population north of Point Eugenia for 1979, Baja California, was 131 500 t (Klingbeil, 1979). Ermakov (1996) estimated that the total biomass of chub mackerel in the open ocean area (100 to 150 miles west of the 200-mile EEZs of Mexico and USA between 28 and 40°N) influenced by the California Current was 1.7 million t.

The target strength (TS) per kg of chub mackerel has been determined by several authors. Guzmán *et al.* (1982) determined that the TS_{kg} was -31.3 dB/kg. Johannesson & Vikchez (1979), and Castillo *et al.* (1987), determined a TS_{kg} of -35 dB/kg, using the echosounders SIMRAD EKS-38 and SIMRAD EKS-120.

4.2.2 Changes in abundance

Biological analyses performed during 1966-1984 showed that the abundance of chub mackerel off Western Sahara varied from 0.48 billion individuals in 1974 to 2.74 billion in 1984 (Sedykh & Krivospichenko, 1987). Maxim *et al.* (1990) reported that the chub mackerel biomass off Mauritania decreased from 331 000 t in 1972 to 230 000 t in 1976, increasing after 1982 until it reached 522 000 t in 1988.

Crawford (1981b) reported that off South Africa the increase in chub mackerel coincided with a reduced ***Sardinops ocellata*** stock as a consequence of the introduction of small-meshed (12.7 mm) nets. However, after a number of years, the chub mackerel population declined in a manner similar to that shown earlier by ***Trachurus trachurus*** and ***S. ocellata***, with disastrous results for the industry.

Data on annual fluctuations in abundance of the chub mackerel in the early California fishery are reported by Croker (1933; 1938), Fitch (1951), and Roedel (1952b). Reports on the status of the eastern Central Pacific stock have been published by Frey & Knaggs (1973), MacCall (1973), Knaggs (1974), Knaggs & Sunada (1975), Klingbeil (1976, 1977). Squire (1972; quoted by Schaefer (1980), reported the estimated indices of annual apparent abundance for chub mackerel from 1962 to 1969, based on aerial fish spotters data from Monterey Bay to southwest of San Diego, and occasionally offshore to San Clemente Island, Cortez Bank, and San Nicholas Island. The indices showed an 89% decline in annual apparent abundance from 1963 to 1968. Klingbeil (1976) estimated a total biomass of 8 883 to 19 035 t for 1975.

Jordán *et al.* (1978), Tsukayama (1983) and Zuta *et al.* (1983) reported a population estimate of 1.9 to 1.5 million t of chub mackerel off the coast of Peru for the period 1978-1991. They report this as a 138% increase in biomass from the previous year, with a substantial number of younger fish entering the fishery. Seventy percent of the population was distributed from Callao to the north. The greatest density of this species was found within 30 miles of the coast. Off the north of Chile, chub mackerel is more abundant during summer, coinciding with the reproductive season and spawning (Böhm *et al.,* 1984). Between 1976 and 1984, there was a notable increase in fishing of chub mackerel in northern Chile. Nevertheless, during the 1982-1983 El Niño, chub mackerel were not caught. In contrast, species like ***Katsuwonus pelamis***, ***Sarda chiliensis***, and ***Coryphaena hippurus***, were caught in spite of not being habitual in the area (Cañón, 1985).

Chub mackerel have been declining in the Sea of Japan since 1962. However, the Pacific population increased rapidly since 1958 and has replaced the Pacific saury (***Cololabis saira***) as the dominant species (Fukushima & Ogawa, 1988). Egg abundance and recruitment levels indicated that the relatively abundant age-classes of chub mackerel were generated from low spawning biomasses between 1954 and 1957, when the stock began to expand (Tanaka, 1983). Watanabe (1970) reported that there was a remarkable increase in the landings from off the Pacific coast of Honshu in 1960, and that the catches have remained at a high level since then. Tanaka (1983) concluded that chub mackerel formed a single dominant species around 1970 when sardine (***Sardinops melanosticta***) collapsed. This author showed that the coefficient of variation of chub mackerel abundance was fairly large at about 50%, showing considerable long-term changes.

4.3 Natalaty and recruitment

4.3.1 Reproduction rates

Parrish (1974) reported that spawning success is aperiodic and varies in series of about 2 to 10 or more years. According to Klingbeil (1977), the 1976 spawning season was the most successful in over a decade off California, and the spawning population was greater than 9 000 t. He suggests that as a result of the strong 1976 year-class, the total biomass increased by a factor of five or six. In the Gulf of California, there is a great disparity in the estimations of spawning biomass. Moser *et al.* (1974) calculated approximately 500 000 t of spawning biomass for February 1956, 300 000 t for April 1956 and February 1957, based on eggs abundance. Martínez-Aguilar & Anda-Montañez (1990) reported 37 951 and 6 620 t based on eggs and larvae estimations, respectively. Green-Ruiz & Aguirre-Medina (1992), using larval abundance, reported that the estimated spawning biomass of chub mackerel in 1978 was 165 908 t.

In Japan, spawning abundance is estimated every year since 1951 (Watanabe, 1972; 1982; 1983; Tanaka, 1983). The magnitude of the spawning stock off the Pacific coast of Japan increased markedly around the late 1950s from an extremely low of about 30 million eggs spawned, to a peak of 650 to 780 million from 1962 to 1966. After a temporary but sharp decline down to 160 to 190 million around 1970, spawned egg abundance increased again quite remarkably and reached a maximum of 960 to 1 020 million eggs during the mid-1970s. Egg abundance showed a declining trend thereafter and was about 270 million eggs in 1981.

4.3.2 Recruitment

Off South Africa, nought-year-old chub mackerel are fully recruited in January of each year, seven months after the initiation of spawning by the start of the fishing season. Availability remains at a moderate level until May (Crawford, 198 a) inshore along the west coast in much the same region as adult round herring ***Etrumeus teres*** (Crawford, 1983).

Perrotta & Pertierra (1993) estimated that the recruitment to the fishing area of the Mar del Plata (Argentina) varied between 8 and 150 million individuals from 1981 to 1990.

Chub mackerel have been recruited into the California fishery as 1-year-olds during most years, but since 1965 the proportion of age-0 fish in the catch has increased comprising over 65% of the landings in 1967 (Parrish, 1974). Mean recruitment during 1929 to 1996 was 639 million fish, ranging from a low of 3.5 million in 1969 to a high of 8.970 million in 1981 (Parrish, 1974; Parrish & MacCall, 1978; Yaremko *et al.*, 1997). However, Parrish & MacCall (1978) observed that the recruitment strength is much less variable when spawning biomass is greater than 91000 t. All of the disastrously poor recruitments of 91 000 t or less were produced by spawning stocks of less than 91 000 t. Estimates for the 1996 year-class recruitment (164 million fish) was less than one-half that of 1995 (395 million), and the lowest since 1975 (Yaremko *et al.*, 1997). In the Gulf of California (Mexico), Cisneros *et al.* (1990) reported that the maximum recruitment should be in spring (April). Off Vizcaino Bay (Mexico), Gluyas-Millán & Muñoz-Gómez (1993) detected that annual recruitment to the fishery occurred between November and April, whereas the older and larger fish were caught between May and August.

Watanabe (1970) states that recruitment within a stock of a constant biomass may be governed by egg abundance fluctuations due to age and physiological condition of the parent fish and to mortality rates in the early stages of life. The relationships of egg abundance to recruitment into the fishery are discussed by Watanabe (1970; 1983). Year-class strengths of chub mackerel were highly dependent upon annual egg production, which in turn was apparently affected by the stock abundance of the chub mackerel and sardine (***Sardinops melanosticta***) over the previous two or three years. Delayed intraspecific density effects on egg production seemed to operate strongly until the late 1970s. However, after the sardine stock increased significantly (i.e. 1980s) the per capita annual egg production of chub mackerel did not recover in spite of a decrease in the stock size, possibly due to the delayed density effects of the sardine stock (Kishida & Matsuda, 1993).

Off Korea, zooplankton biomass appeared to be lower in the 1970s than in the 1980s. From then onward, zooplankton biomass and chub mackerel recruitment had a positive relationship during 1975 to 1989, and it is likely that the high level of chub mackerel recruitment in the 1980s was attributed to the high zooplankton density. Kim *et al.* (1995) found that the relationships between fecundity of the spawning stock and recruitment in the Korean waters were well fitted to Ricker's reproductive curve.

4.4 Mortality and morbidity

4.4.1 Mortality rates

Watanabe (1970), performed eggs and larvae surveys and estimated that only 22% of spawned eggs survived at time of hatch out, 3.9% at the end of prelarva, 1.6% at the stage of 3.7 mm TL, and 0.42% at the 4.5 mm stage. The survival rate from spawning to 15 mm TL is 0.051%, and 0.014% to 30 mm TL. This author pointed out that the survival of larvae may partly be governed by the quality of eggs derived from the parents.

Maxim *et al.* (1990) reported that the rate of natural mortality (M) and the instantaneous annual fishing mortality rate (F) of chub mackerel caught off Mauritania in 1988 were 0.4 and 0.383 year^{-1}, respectively. However, Barkova & Krivospitchenko (1990) reported that M was 0.6 year^{-1}. The average F calculated between 1979 and 1987 was 0.13, 0.31, 0.51, 0.55, 0.69 and 0.67 year^{-1} for age classes I to VI, respectively (Barkova & Krivospitchenko, 1990). The average F per age class between 1982 and 1985 in northwest Africa varied from 0.326 year^{-1} in 1-year-old fish to 1.155 year^{-1} in 6-year-old fish. The oldest individuals (8 years or more) were subject to a F of 0.343 year^{-1} (FAO, 1990).

The assumed age composition of chub mackerel during its first year of exploitation off South Africa (1954), suggests a M of 0.43 year^{-1} (Crawford *et al.*, 1979; Crawford, 1980). The value hitherto adopted for the South African fishery has been 0.25 year^{-1} (Centurier-Harris, 1977). Catchability coefficients from 1964 to 1976 varied between 0.00013 and 0.00203 (mean 0.00041±0.00052) (Crawford, 1980).

In waters of northeastern Venezuela, Mendoza (1993) estimated that M and F for chub mackerel were 0.58 and 0.02 year^{-1}, respectively. Castello & Cousseau (1976) reported a Z (instantaneous annual total mortality rate) of 0.907 year^{-1} for chub mackerel off Argentina, with M = 0.330 year^{-1} and F = 0.577 year^{-1}. However, these authors suggested that those mortality rates were overestimated, because of the progressive lack of older individuals in the fishing grounds due to changes in the migratory routes. Perrotta *et al.* (1990 b) observed that M varied between 0.43 and 0.53 year^{-1}, although they considered that the last value was an overestimate. These authors calculated M as 0.428 year^{-1} using 7 years as age limit (age surpassed only by 5% of the population). Perrotta & Pertierra (1993) estimated a M of 0.375 year^{-1}, using 8 years as the age limit, having in mind that the maximum age was 12 years. These authors estimated that from 1981 to 1990 F varied between 0.12 and 0.75 year^{-1}.

In the Northeast Pacific, tag-recapture methods provided direct estimates of M for chub mackerel in southern California (Fry & Roedel, 1949). Estimates of M ranging from 1.1 to 1.3 (year^{-1}) were obtained depending on method of analysis and assumptions of tagging mortality rates. However, this high mortality (loss of 70% per year) was inconsistent with the age frequency in the catches particularly for the early years of the fishery when older fish were common (Parrish & MacCall, 1978). Fitch (1951) suggested a probable range of M from 0.3 to 0.7 year^{-1}. Parrish & MacCall (1978) suggest that M is probably between 0.4 and 0.6. An abundance index based on autumn surveys during 1950 to 1961 (Mais, 1974) was used by Parrish & MacCall (1978) to derive an effort index. Estimates of F and Z calculated via cohort analysis by Parrish & MacCall (1978) using M=0.5, Z variated between 0.729 year^{-1} from 1954 to 1955 and 2.056 year^{-1} from 1957 to 1958. Parrish (1974) reported a trend of increasing fishing mortality rates in the eastern Central Pacific fishery, especially for age-groups 0 and 1. Fishing mortality for age-group 1 exceeded 0.5 in 1964; fish of age-group 0 were almost entirely unexploited before 1965. Yaremko *et al.* (1997), assumed that age-specific fishing mortality during the first and second quarters of 1997 was equal to the average values for 1991 to 1996, and that M=0.5 remained unchanged. Cisneros *et al.* (1990) determined that M was 0.61 for chub mackerel in the Gulf of California, whereas Nevárez-Martínez *et al.* (1994) reported that M ranged between 0.635 and 0.688 year^{-1}, Z between 1.156 and 4.536 year^{-1}, and F between 0.47 and 3.90 year^{-1}. Off Chile, Serra (1983) estimated M as 0.3 year^{-1} at 18°C.

In the northwestern Pacific Ocean, Belyaev & Rygalov (1986) found that the survival rate of eggs decreased as they moved farther from the coast, probably due to a stronger mechanical action of the waves in the oceanic regions at later developmental stages when the eggs are located in the surface layer. Watanabe (1983) observed that the fishing mortality coefficient of the chub mackerel subpopulation along the Pacific coast of Japan tends to increase when stock number decreases. This author assumed that M was 0.5 year^{-1} throughout the period 1961-1978 and F fluctuated between 0.044 year^{-1} in 1963 and 1.074 year^{-1} in 1976. For chub mackerel off Taiwan Province of China, Zhenbin *et al.*, (1991), reported that Z =1.017 year^{-1}, M =0.6277 year^{-1} and F=0.3893 year^{-1}.

4.4.2 Factors causing or affecting mortality

Mianzan *et al.* (1997) reported a mass mortality of chub mackerel in Argentina during the spring of 1993. All dead fish had salps in the stomach contents. The salps contained high concentrations of the toxigenic dinoflagellate ***Alexandrium tamarense***.

Zama *et al.* (1984) reported a mass mortality of adult chub mackerel in January 1983 in Puerto Chacabuco, southern Chile. Chub mackerel seem to have been lured into Aysen Fjord by higher water temperature and to have died around Puerto Chacabuco due to a combined effect of low salinity above a halocline and low dissolved oxygen below it. A similar event was reported by Clement (1988) in the Reloncavi Fjord (Chile) during 1985. The artificial discharge of continental waters into the fjord might have been responsible for a mass mortality of chub mackerel due to changed environmental conditions.

4.5 Dynamics of the population

The stock of chub mackerel off northwest Africa (fishing areas 3.4.1.3 and 3.4.3.1) was estimated at 2 060 million individuals between 1979 and 1985 using a virtual population analysis (VPA). Of these, 41.6% were 0-year-olds, and 0.04% were 8 or more years old. The mean total biomass was estimated in 341 949 t and the spawning biomass in 203 521 t (FAO, 1990). On the other hand, Krivospitchenko (1986) and Barkova & Krivospitchenco (1990), using a VPA analysis, estimated that the mean biomass of mackerel in the area between Western Sahara and Mauritania was 423 000 t (2 514 millions of individuals) from 1972 to 1987. Elwertowski *et al.* ,(1972; quoted by Troadec & Garcia, 1979) gave a maximum equilibrium catch of 170 000 t for the stock of chub mackerel.

Estimates of the potential maximum sustainable yield for the offshore chub mackerel stock off South Africa, suggested that the annual long-term yield is in the order of 25 000 t per year, and the inshore chub mackerel catch should be limited to 55 000 t (Baird, 1975). The annual yield should therefore, ideally consist of 25 000 t of the offshore and 55 000 t of the inshore components. The VPA suggests that strong recruitment of chub mackerel occurred during 1966 and 1967. High chub mackerel catches were landed between 1967 and 1969, when much of the harvest was netted close inshore (Crawford, 1981b). Crawford (1983) suggest that it is possible that environmental factors may have resulted in increased availability of chub mackerel to the purse-seine fleet during this period. On the other hand, offshore catches of adults peaked during 1966 and 1970 at about 60 000 t before declining to negligible quantities by 1975 (Baird, 1978a). Crawford & De-Villiers (1984) reported that off South Africa, an exceptionally strong year-class appears to have occurred in 1977 an to have been largely responsible for a peak catch of about 200 000 t in 1978.

Perrotta (1990) and Perrotta & Pertierra (1993) concluded that chub mackerel off Argentina was underexploited after estimating biomass and maximum surplus yield during the period 1981-1990, using M=0.33-0.53 year^{-1} and F=0.12-0.75 year^{-1}.

Parrish & MacCall (1978), using a value of M= 0.5 year^{-1}, found that the maximum yield per unit weight of recruits occurred at an age of 1 or less and at the highest instantaneous fishing mortality rate of 1.0. This does not mean that there should be heavy fishing on 1-year-olds, as that would result in a minimal spawning biomass per recruit (Parrish & MacCall, 1978). These authors showed that high exploitation rates cause little reduction in yield at ages of recruitment of 3 to 4. However, the age at recruitment during most of the observed past fishery has been 1. Parrish & MacCall (1978) noted that the Ricker functions predict that extinction will occur if the age at recruitment is 1 or lower and the exploitation rate exceeds 0.6. Parrish (1974) reported that during the collapse of the chub mackerel population of the late 1960s the exploitation rate exceeded 0.6 and the age at recruitment was less than age-1. MacCall *et al.* (1985) reported that the high abundances of the 1930s and 1980s are remarkable events in the history of the fishery. The paleosedimentary record of chub mackerel scales in the Santa Barbara Basin (Soutar & Isaacs, 1974) shows two peak periods of deposition since 1800. One is in 1925 to 1935, corresponding to the known abundance peak at that time, and the other around 1830. Jacobson *et al.* (1994) used VPA to estimate that the biomass of chub mackerel of the eastern Central Pacific increased during 1978 to 1982 to the highest level on record (752 000 t); the declining biomass after 1982 was due to lower recruitment. MacCall *et al.* (1985) concluded that the level of abundance from 1978 to 1982 was a rare event. Abundance declined to less than 100 000 t by 1993 (Jacobson *et al.* 1994). Abundance data and biomass indices during recent years were affected by ENSO conditions. Thus the conditions of 1993 appear similar to those in the mid-1940s, when chub mackerel declined to biomass levels less than 100 000 t after a period of high abundance (Prager & MacCall, 1988a; 1988b). After 1945, stock biomass varied around an average of about 70 000 t until the fishery collapsed in 1965. Based on a California Department of Fish and Game projected biomass estimated of 91 200 t for 1 July 1997, Yaremko *et al.* (1997) recommended 21 768 t as commercial fishery quota for the 1997-1998 fishing season. Yaremko *et al.* (1997) suggested that the current biomass of chub mackerel is smaller than in the 1980s. Landings from

California and Ensenada (Mexico) have decreased sharply, and catch rates from southern California commercial passenger fishing vessel fleet have also declined. The 1997 biomass estimate is higher than the previous year's estimate of 47 160 t, because there were more fish in the older year classes than previously estimated (Yaremko *et al.*, 1997)

Watanabe (1983) estimated that a parental spawning level of 200 million eggs is the minimum which would ensure that the stock abundance of the Pacific subpopulation of Japan would be kept at a safe level. Matsuda *et al.* (1996a) estimated the stock in number of chub mackerel in the Pacific Ocean off Japan during 1970 to 1988 by VPA. They also calculated the number of eggs spawned by all adults using age-dependent per capita fecundity. The Fisheries Agency of Japan compared yearly egg production estimated by VPA against egg production estimated with plankton surveys, and found that the yearly egg production estimated by plankton surveys has greater year to year fluctuations than VPA estimates. Honma *et al.* (1987) and Matsuda *et al.* (1996a) suggest that either the per capita fecundity is much smaller than considered before or the egg production survey underestimates the yearly egg production at least when the stock is low. Honma *et al.* (1987) reported that the population size of chub mackerel, calculated by cohort analysis, has been at an exceptionally low level with about 3 billion fish at age one. The adult population also decreased to 2.3 billion fish in 1984.

In waters off Yemen (Gulf of Adem), VPA estimates of chub mackerel stock size are 50 000 to 60 000 t. Total allowable catch as well as possible catch is recommended to be from 11 000 to 13 000 t (Kukharev, 1993).

5. EXPLOITATION

5.1 Fishing equipment

5.1.1 Gears

In Costa de Caparica and Fonte da Telha (Portugal), chub mackerel is caught using a beach seine called "xavega". About 90% of the total artisanal fishery catches are caught with the xavega. The main catch is horse mackerel, followed by chub mackerel, sardine, squid and sole (Franco & Costa, 1979). Small purse seines called "rapas" are also used in adjacent waters of the Sado Estuary (Portugal) (Dias & Cabral, 1991). In the Canary Islands, chub mackerel (15 to 25 cm TL) are caught year-round, specially in the south of the islands, using lure lights and a purse seine called "traiña". Smaller fish are caught using a circular net (about 2 m +) called "gueldera" and bigger fish are caught using longline (Bas *et al.* 1995). Along the continental coasts of northwest Africa, chub mackerel is mainly caught with trawl (Domanevsky, 1970), although purse seine is also important.

Until 1975, catches of chub mackerel in the southeast Atlantic were mainly made by purse-seine vessel off the western Cape, South Africa, but subsequently by midwater or demersal trawlers fishing primarily off Namibia (Crawford & De-Villiers, 1984).

Off Argentina a small purse seine known locally as "lampara" is used for chub mackerel (Perrotta, 1988a; 1992). This gear was introduced in Argentina by Italian fishermen in 1940. A "lampara has two big wings of 84 m each, with mesh sizes of 840, 420 and 210 mm. The central part is about 82.8 m long and composed by nets with mesh sizes of 111, 40 and 20 mm. The fishing operation is carried out on the left side of the boat (Perrotta, 1988a). Off Mar del Plata, chub mackerel are lured toward the sea surface using bait, in order to make the gear effective. The bait mainly consists of previously salted anchoita heads and residues of mackerel and rough scad (***Trachurus lathami***). Some hours before fishing starts, all fish residues are cooked on board (Perrotta, 1988a; Izzo & Boccanfuso, 1993).

The fishing gears used historically to catch chub mackerel in the eastern Central Pacific are reviewed by Fry (1931), Croker (1933, 1938), Scofield (1951, quoted by Schaefer, 1980), Roedel & Joseph (1954), Messersmith & Hyatt (1965), and Knaggs (1972). Lampara nets and scoop nets contributed significantly to the catch in previous years but the present fishery uses primarily purse seines. Sport-fishing gear captured a larger number of chub mackerel from 1971 to 1974 than commercial gear in California (Schaefer, 1980).

In waters of Ecuador, Peru, and Chile chub mackerel is captured almost exclusively with purse seines, although gill nets have also been used off Peru (Schaefer, 1980). The fishing gears utilized in Peru, in order of importance, are purse seines, gill nets, and midwater trawls. More than 80% of the chub mackerel has been captured by purse seines (Jordán, 1979; quoted by Schaefer, 1980). Serra (1983) reported that between 1970 and 1981, there was a gradual improvement in fishing equipment used in northern Chile, such as the incorporation of the power block, fishing pumps, acoustic equipment, larger nets, aeroplanes for surveying activities, and collaboration in fishing operations. In 1978, the 13 mm mesh-size anchovy net was replaced by a 38 mm mesh-size sardine net. The replacement of practically all nets was completed by the end of 1979. In Talcahuano, the original anchovy nets were replaced in 1969 by jack mackerel nets with a mesh size of 50 mm.

In Japan, purse seining is the principal method for the capture of chub mackerel (Tanaka, 1983), but lampara nets, set nets, trap nets, gill nets, large drift nets, spoon nets, trolling, balance fishing, stake lines, long-lines, and skip fishing are also used (Schaefer, 1980). During the feeding season in summer and autumn, mackerel are caught by the purse-seine fishery off Hokkaido and northern Honshu. During the wintering and spawning seasons they are caught by angling and scoop nets in waters off central Honshu and the Izu Islands (Tanaka, 1983). Purse seines are also used in Korea (Park & Choi, 1995). Tomiyama & Mibayo (1976; quoted by Schaefer, 1980) provide descriptions and photographs of some of the above gear and the techniques used in the Japanese chub mackerel fisheries. Chub mackerel spearing is one of the traditional fishing techniques in Japan. It is very interesting from the view point of fishing technology because of its primitive but highly developed luring technique (Kawamura & Takahashi, 1977). In spearing chub mackerel, a relatively large wooden or cloth luring model fish of about the same size of a chub mackerel are used to attract fish up to the sea surface at the spearing position. Though chub mackerel try to feed on a lure, they come near the luring model fish and stay around it recognizing the model fish as a schooling position. Akiyama *et al.* (1995) made underwater observations of chub mackerel behaviour to trolling line.

Kanda *et al.* (1978) studied the selectivity curve of the hook-and-line fishing for chub mackerel. The maximum catching efficiency seemed to be 26 cm FL for N1 12 hook, 30 cm FL for N1 14 hook, 34 cm FL for N1 17 hook, respectively. Anglers of longer experience obtained the largest catches as they required relatively shorter time to take the fish off the hook and because they have the skill to strike a fish. Ling *et al.* (1982) concluded that the optimum mesh size of gill nets for chub mackerel in the Yellow Sea and Bohai Sea was 90 mm.

5.1.2 Boats

Off northwest Africa, the fishing fleet of the ex-USSR that operated between 21 and 24°N was composed by pelagic trawlers of the type RTMS (102 m, 3 800 HP), RTMA (82 m, 2 350 HP), BMRT (85 m, 2 000 HP), and purse seiners of the type SRTM (54 m, 800 HP) (FAO, 1990). The fishing fleet that operated off Mauritania in 1989 was composed by 12 vessels of Rumania (3 163 t of capacity and 3 880 HP) and 27 vessels of the ex-USSR (2 400 to 3 019 t of capacity and 2 000 to 3 880 HP) (FAO, 1990). In 1981, the artisanal purse seining fleet of Morocco was composed by 212 boats of approximately 52 t of capacity, distributed between the ports of Safi, Essaouira and Agadir (Belvèze, 1986). These boats were equipped with echo-sounders and power-block. In 1983, the horizontal sonar was introduced. Marchal (1967) described the purse-seining fleet operating in waters of the Côte d'Ivoire.

The fleet that fished on chub mackerel in waters of Argentina was composed by 120 small boats ranging from 50 to 200 HP, 9 to 16 m length, 2.8 to 4 m width and 6 to 12 t of capacity. Since 1980, most of the boats have improved their fishing equipment (i.e. echo-sounders, new engines) (Perrotta, 1988a; Perrotta, 1992; Izzo & Boccanfuso, 1993). These boats are equipped with VHF radio, so they receive information of where the schools have been detected by other fishermen. Flocks of petrels and albatross were used to detect the mackerel schools before the introduction of the echosounders (Izzo & Boccanfuso, 1993).

In California, by 1934 a majority of the net boats were over 16 m in length and some were nearly 30 m. Catches made by the net boats fell off in the years following 1935 and by 1939 the seiners alone were no longer able to meet the demand. A large fleet of small boats carrying crews of one to three men filled the gap. After 1950 this fleet was forced to abandon the fishery (Fitch, 1953). The purse-seiner range in capacity from 18 t to 73 t and from 15 to 30 m in length. Smaller boats of 10 to 15 m and maximum capacities of 27 t utilizing gear other than purse seines, were still operating in 1976 (Schaefer, 1980). Ninety-three percent of California's landings during 1996 were made by approximately 17 purse-seine vessels based in the Los Angeles area, commonly known as the "wetfish" fleet. Twelve additional wetfish vessels based in Monterey accounted for the remaining 7% of landings in northern California (Yaremko *et al.*, 1997).

The purse seiners fishing for chub mackerel off Ecuador, Peru, and Chile range in capacity from 14 to over 270 t. Most of the fish caught off Peru are taken by vessels of 100 to 300 t. The Chilean fleet is composed of boats of the Pacific coast seiner-type. Between 1962 and 1965, this fleet grew from less than 251 to a record of 560 units. The fleet decreased to 100 units in 1974 but good fishing conditions from 1975 onward stimulated a new expansion of the fleet, which increased to 158 boats in 1981. The seiner fleet in the northern zone of Chile is composed of three small fleets, which operate out of the most important ports (Arica, Iquique and Antofagasta). In the years 1980-1981, the average fish hold capacity reached 250 m^3 (Serra, 1983). In Talcahuano, the fleet was composed by 48 boats in 1969, declining in 1972, then increasing and stabilizing between 1974 and 1976 at an intermediate level of 37 to 39 boats. Subsequently, it continued to increase reaching a total of 56 boats in 1981 (Martínez *et al.*, 1982, Serra, 1983). In 1965 the average capacity of fish holds was approximately 50 m^3 reaching 120 m^3 in 1970 and remaining relatively stable until 1980 when it reached 152 m^3 (Serra, 1983).

In Japan, there is a wide range in the size and type of boats used for catching chub mackerel, from 5-m skiffs to a fleet of 100-t purse seiners, which lands most of the fish (Schaefer, 1980). Tanaka (1983) reported that purse-seine boats are large and powerful and that catches of 400 of sardine in one haul are not rare in summer and autumn.

5.2 Fishing areas

5.2.1 Geographic range

The most important fishing area for the ex-soviet fleet off northwest Africa was between 26° and 14°N, however, mackerel occurred in trawl catches in the area from 28°N to Cape Verde. Chub mackerel are scarce in the catches towards the north and as a rule occur in small quantities only (Domanevsky, 1970). Parcalaboiu (1971) reported that in January, catches of the Romanian fleet were confined to the 23 and 29°N parallels, but increased in February along parallel 22°N, in March along 25°N and in April along 26°N. In August, mackerel was fished again along 25 and 23°N, and in September fish were caught between 26 and 21°N. The fishing area for mackerel of the artisanal fleet of Morocco is located between 28 and 30°N (Belvèze, 1986).

Off South Africa, catches of chub mackerel have been made all along the western Cape coast since 1954 (Baird, 1975). This area includes the fishing grounds in which all other pelagic species are exploited. During all years the largest proportion of the annual chub mackerel catch was made in the area between Lamberts Bay and Robben Island (Baird, 1975). Near-shore catches have been made as far north as the Orange River and eastward to Cape Infanta, but records north of latitude 31°S or east of Quoin Point were infrequent, with most fishing for chub mackerel confined to the intervening areas. Hecht (1976) noted that the demersal fishery off eastern Cape coast caught small quantities of chub.

Perrotta (1988a) concluded that the fleet that fishes off Mar del Plata (Argentina) operates in an area where chub mackerel shoals are scarce, so the probability of being captured is very small. During the 1960s the radio of action of the fleet largely surpassed the 50 m isobath, where there were clues of a major abundance of chub mackerel (Perrotta, 1987; Perrotta, 1988b). From 1976, the fishing area decreased progressively due to the crisis of the fishing industry (Forciniti *et al.*, 1988).

The eastern Central Pacific fishery is conducted primarily off southern California and Baja California. Crooker (1933 and 1938) and Roedel (1952b) describe the fishing areas off California from 1928 to 1951. From 1968 to 1970 most fishing was conducted in southern California around Santa Catalina and San Clemente islands, and nearshore from San Pedro to San Diego (Knaggs, 1972a). The Mexican fleet has caught chub mackerel mostly in the area of Vizcaino Bay, Baja California, but extensive catches have been made in the Gulf of California (MacCall, 1973).

Pelagic fisheries in Chile are located between the border with Peru and 37°10'S (Serra, 1983). The main fishing grounds are located off Arica, Iquique, Antofagasta, Talcahuano and Coquimbo (Subsecretaría de Pesca de Chile, 1983; Aguayo & Steffens, 1986). Catches are mainly obtained along a 60-nautical mile coastal strip, although sometimes further of 80 miles. However, catches obtained by a fleet of Soviet factory ships indicate that the species is found also beyond the 200 miles zone (Serra, 1983; Oliva, 1989). Off Ecuador, the major concentrations of chub mackerel are reported in the north and northwest of the Gulf of Guayaquil (1°05'N to 3°30'S) (Pizarro de Rodríguez, 1983).

Ouchi & Hamasaki (1979), Schaefer (1980) and Tanaka (1983) mention several principal fishing grounds around Japan. These are grouped as Goto west group (East China Sea northern group), China mainland group (East China Sea western group), East China Sea southern group, Pacific western group, Pacific group and Tsushima group (southern Japan Sea and northern Japan Sea groups). Tanaka (1983) reported that fishing grounds are generally developed in coastal waters but are extended to offshore areas in the East China Sea. Limbong *et al.* (1991) reported that fish concentrations with high CPUE appeared in the southwestern Japan Sea from November to December. They expanded to the waters near Cheju Island from January to April and virtually disappeared in summer. Park (1977) and Park & Choi (1995) observed that the major fishing ground for chub mackerel in waters adjacent to Korea was formed around Jeju Island in winter, in the Yellow Sea in summer, and in the Eastern Sea of Korea in autumn. Song *et al.* (1995) reported that the traditional fishing ground of chub mackerel in Qionghai Sea of Hainan Province (China) was located almost in the upwelling area (18°30'N and 111°30'E between April and September). D'yakov *et al.* (1984) reported that commercial concentrations of chub mackerel were found to be confined to cyclonic eddies. However, Park & Choi (1995) reported that in Korean waters, fishing grounds were mainly formed in the southern area of the temperature front, and high CPUE of chub mackerel obtained by the purse-seine fishery was related to the horizontal temperature gradient. Fishing grounds tend to be formed near the thermoanticline structure, which consists of surface warm water originating from the Tsugaru Warm Current Gyre or the Kuroshio Current and intrusive Oyashio Current cold water in lower layers. These structures are detected as “cold-wedge” or “frontal-wave” patterns on satellite infrared images (Hirai *et al.*, 1988; Hirai, 1991). The optimum surface-water temperature for chub mackerel showed a large seasonal fluctuation: 11 to 16°C from January to March, 12 to 19°C from April to June, 22 to 30°C from July to September and 14 to 24°C from October to December (Park & Choi, 1995). Hirai *et al.* (1988) and Okuda *et al.* (1988) developed a method for short-term prediction of fishing grounds of southward migrating mackerel formed in the waters of Sanriku in northeastern Japan, utilizing satellite infrared images. Fishing grounds of chub mackerel were closely related to the evolution of meso-scale hydrographic phenomena, such as disturbances occurring near the front of the Tsugaru Warm Current or warm core ring.

5.2.2 Depth ranges

Off northwest Africa, the ex-soviet fleet operated at depths of 100 to 300 m (Domanevsky, 1970). The fishing area for mackerel of the artisanal fleet of Morocco is located over the 50 and 200 m isobaths (Belvèze, 1986). Maxim *et al.* (1990) reported that in 1988, catches off Mauritania took place at depths between 45 and 100 m. Off Senegal, chub mackerel occurred in waters from depths of 60 to 105 m (Klimaj, 1970).

According to Baird (1975) small chub mackerel (10 to 25 cm in length) were caught inshore, in the same fishing area where other pelagic species are usually caught. The bulk of catches of medium-sized chub mackerel (26 to 45 cm in length) was usually made in St. Helena Bay and farther south as far as Dassen Island. Larger chub mackerel appear with remarkable regularity during each winter in an area 20 to 30 nautical miles northwest of Cape Columbine in relatively deep water (>100 m) where most of the catches of this offshore component of the chub mackerel stock are made. Some catches are also made further south in the vicinity of Dassen Island. Crawford (1981b) reported that offshore catches took place on the St. Helena Bay, Saldanha Bay or Hout Bay grounds.

Off Argentina, Perrotta & Christiansen (1993) observed that there was little coincidence between the fishing areas and the distribution area of schools, and that the majority of null catches was obtained at depths shallower than 20 m.

This species was abundant in waters of Peru at 50 to 140 m of depth (temperature at these levels is 16 to 20°C) above the shelf and continental slope (over depths to 1 025 m) (Kotlyar & Abramov, 1983).

5.3 Fishing seasons

In waters of Mauritania, the fleet of the ex-GDR (German Democratic Republic) obtained the greatest yields from May to July and from October to December (Holzlöhner, 1990b). On the fishing grounds off Senegal (northwest Africa), chub mackerel is of great importance in trawl catches in March, April and May, but catches decline in June and July (Klimaj, 1970).

Off South Africa, although CPUE levels greater than 10 t of nought-year-old fish per standard-boat-day have frequently been found during the period January-May, they have never been recorded for winter months. One and 2-year-old chub mackerel are also most available during summer and autumn, catch rates declining to a lower level in winter. CPUE levels greater than 25 t per standard-boat-day have been most frequently recorded in summer and autumn, but equally rewarding fishing has taken place in some months during winter and early spring, especially since the introduction of aerial fish spotting in 1967. Availability indices show a noticeable peak of 3 to 5-year-old chub mackerel in July and lower levels during other months (Crawford, 1981a).

Off Argentina, the chub mackerel fishing season goes from October to March, but since the economic crisis emerged in 1976, the fishing period was reduced to November to February (Forciniti *et al*, 1988; Perrotta & Pertierra, 1993).

Roedel (1952b) reviews the seasonal catches of chub mackerel off California during 1928 to 1951. During this period, fish were most abundant off southern California in the fall, progressively scarcer during the winter, and virtually unavailable by March. During 1930 to 1940 landings from May to August comprised 24 to 47% of each season's total catch. Parrish & Knaggs (1972) reported that during 1964 to 1965 through 1967 to 1969 the fishing season extended from 1 May to 30 April the following calendar year. Parrish & MacCall (1978) state that in the later years of the fishery the catches became sporadic, and there was no seasonal pattern.

Off Ecuador, chub mackerel appear around December, with peak catches during January and February and smaller catches in March. Chub mackerel do not become abundant again off Ecuador until the following December (Cole, 1979; quoted by Schaefer, 1980). Off Peru, the best catches of chub mackerel are made from July to November on the northern fishing grounds and from January to April on the southern fishing grounds (Doucet, 1965, quoted by Schaefer, 1980). Jordán (1979), quoted by Schaefer (1980), reported the fishing season to be from September to December.

In the northwestern Pacific, the fishing seasons cover the whole year, although they change depending on the fishing ground. The Pacific group is mainly fished from May to December, the Pacific western group is fished specially during the summer, the Tsushima group is fished in spring and autumn, while in the southern grounds fishing is developed year-round (Schaefer, 1980). The purse-seine fishery, which is the most important, produces its greatest catches in the summer and autumn (Usami, 1976; quoted by Schaefer, 1980). Off Korea, chub mackerel fishing is carried out from January to April and November to December (Park, 1977).

5.4 Fishing operations and results

From the economic point of view, ***Scomber japonicus*** has a great importance in world-wide fisheries. In 1978, the chub mackerel ranked third in importance in world catches (3.4 million t), after ***Theragra chalcogramma*** (3.9 million t) and ***Mollotus villosus*** (3.5 million t). In 1979 and 1980, it ranked fourth and fifth, with 2.8 and 2.6 million t respectively (Mendo, 1984; FAO, 1997). The catch in

1989 was 1.6 million t, 0.9 million t in 1992 and 1.5 million t in 1995 (FAO, 1997) (Table 9). The total landings of chub mackerel in the Pacific Ocean were estimated to be 3.1 million t for 1978 (Table 9), more than the 2.5 million t of tunas, bonitos, and billfishes landed world-wide during the same year (Schaefer, 1980; FAO, 1997). According to Dávila-Fernández (1985), in 1981 chub mackerel represented 3.09% of the total word catch of marine fishes, 34.47% of the total catch of scombrids and 63.86% of the catch of the genus ***Scomber***.

In spite of annual variations, the mean world-wide capture of chub mackerel has been approximately 1.87 million t since 1967 (FAO, 1997). Between 1978 and 1983, there was a decline in the catches, which recovered subsequently between 1984 and 1986, decreasing again to a record low of 962 978 t in 1992. Between 1993 and 1995 catches were close to 1.5 million t (FAO, 1997) (Table 9).

Among the countries dedicated to fish this species during the 1960s, Japan was first with 62.8% of the world-wide catches, followed by China (9.4%), South Africa (6.4%) and the ex-USSR (5.3%). In the 1970s, the total catch increased 2.5 times, when Japan obtained 56.9% of the world-wide catch, followed by the ex-USSR (13.9%), Ecuador (9.3%) and China (5.2%). During the 1980s, the world-wide catch declined although Japan continued to be the leader with 41% of the total, followed by the ex-USSR (18.7%), Ecuador (11.3%), China (7.9%) and Korea (6.2%). From 1990 to 1995, Japan obtained 32% of the world-wide catch, followed by China (20.7%), Korea (11.1%) and Chile (8.6%) (FAO, 1997) (Table 10).

Captures in the northeast Atlantic (FAO Fishing Area 27) were 1 786 in 1981, representing 0.02% of total fish species landed in the area (Davila-Fernández, 1985). In the Mediterranean and Black seas (FAO Fishing Area 37), chub mackerel represented about 0.5% of total fish species landed in 1981 (Davila-Fernández, 1985), ranking 17th among all species in 1991 (Stamatopoulos, 1993c). The total catch of chub mackerel varied from 1 000 t in 1960 to 39 740 t in 1987 (Stamatopoulos, 1993c; FAO, 1997). In the Western Mediterranean, catches oscillated between 142 t in 1972, 16 t in 1982, 2 967 t in 1984 and 171 t in 1991. In the eastern Mediterranean, catches fluctuated between 1 223 t in 1972, 3 967 t in 1982 and 10 460 t in 1991. In the Sea of Marmara and Black Sea, catches varied between 134 t in 1972, 28 730 t in 1987 and 8 906 t in 1991 (Stamatopoulos, 1993c) (Table 11).

During 1964 to 1986 in northwest Africa, chub mackerel represented between 20.7 and 7.3% of catches of coastal pelagic species in FAO Fishing Area 34 (FAO, 1976, 1981, 1988). Chub mackerel catches obtained in Fishing Area 34 varied between 8 300 t in 1960, 325 890 t in 1988 and 55 614 t in 1993 (FAO, 1990; Stamatopoulos, 1993a; FAO, 1994; 1997). According to Davila-Fernández (1985), in 1981 this species represented 5.14% (116 863 t) of the total fish species caught in the area. Furthermore, chub mackerel constituted 34.4% of the catches carried out by the Romanian fleet during 1970 (Staicu & Maxim, 1974) and almost 15% of the Polish catches (Habashi & Wojciechowski, 1973). In 1967, chub mackerel was caught by the Romanian fleet at an average rate of 940 kg/h (5 to 45 t per trawling), with the largest catches recorded in March, August, September and November (Parcalaboiu, 1971). This fleet obtained yields of 2 t per hour south of the parallel 26°N, decreasing the efficiency when approaching the equator. The catches reported by the Romanian fleet in northwest Africa decreased progressively from 34.4% in 1970 to only 14.1% in 1973 (Staicu & Maxim, 1974). From 1974, there was an increase in the mackerel catches landed in Morocco, representing between 45 and 35% of the total catch of pelagic species landed in this country in 1984 and 1985, respectively (FAO, 1990). In 1987, the total catch obtained by the purse-seine fleet (39 boats) that operated off Mauritania was over 450 000 t, from which 6% was chub mackerel. In 1988, the Romanian fleet obtained a catch of 16 749 t of mackerel (13.4% of its total catch of 15 pelagic species), with a fishing effort of 3 042 fishing trips and 52 573 hours of trawling (Maxim *et al.*, 1990). The fleet of the ex-GDR (German Democratic Republic) had catches ranging between 1 800 t in 1982 and 366 t in 1987. The yield per hour of trawling varied between 1 t from 1982 to 1984, and 3 t in 1986, returning to 1 t in 1987 (Holzlöhner, 1990b). This fleet obtained catches varying from 89 t in 1967, to 2 062 t in 1968 and to 139 t in 1971 off Senegal (Holzlöhner, 1990a). The catches reported by the Romanian and ex-USSR fleets for fishing areas 34.13 and 34.31 fluctuated between 87 000 t in 1970, 6 000 t in 1985 and 278 000 t in 1988 (FAO, 1992). The best catches of mackerel by bottom trawl are taken from 1300 to 2000 hours (Domanenevsky, 1970). FAO (1992) pointed out that the population of chub mackerel off Morocco and Senegal seems to be fully exploited, and catches in Côte d'Ivoire, Ghana, Togo and Benin are highly variable. Freon *et al.* (1978) reported that the stock distributed from Guinea-Bissau to Mauritania was overfished in 1976. The major chub mackerel fishing countries according to 1990 production were the ex-USSR (76.8%), Morocco (10.9%), Ghana (3.5%), Portugal (3.3%), and Romania (2.6%), followed by Senegal, Germany, Côte d'Ivoire, Benin, Italy, Equatorial Guinea, Bulgaria, Togo and Mauritania (Stamatopoulos, 1993a) (Table 11).

According to Stamatopoulos (1993a), chub mackerel ranked ninth (1.31%) in landings among all species caught in the southeast Atlantic in 1990 (FAO Fishing Area 47). Chub mackerel was first recorded in the commercial catches of the region in 1954 when 4 044 t were landed. Since then, this

Table 9. Catches of *Scomber japonicus* by oceanic areas (in metric tons)

	FISHING AREA													
	Atlantic, Northeast	Mediterranean & Black Sea	Atlantic, Eastern Central	Atlantic, Southeast	Atlantic, Western Central	Atlantic, Southwest	Pacific, Northeast	Pacific, Eastern Central	Pacific, Southeast	Pacific, Northwest	Pacific, Western Central	Pacific, Southwest	Indian Ocean, Western	TOTAL
1960	1900	1100	8300	31100	-	15100	-	18396	9400	441700	-	-	-	**52996**
1961	5400	1200	15500	53400	-	9900	-	24908	11700	427400	-	-	-	**549408**
1962	12500	1300	37800	27300	-	8600	-	25235	13300	504300	-	-	-	**630335**
1963	6500	1400	49400	35500	-	13100	-	26854	11800	565400	-	-	-	**709954**
1964	8400	4100	77700	69100	200	11800	-	20969	8600	598200	-	-	-	**799069**
1965	30100	5500	51700	45000	400	11400	-	11098	10900	779800	-	-	-	**945898**
1966	12900	2800	46600	63700	300	17400	-	8100	15700	727900	-	-	-	**895400**
1967	16400	3500	77300	140500	400	16100	-	1529	21900	793000	-	-	-	**1070629**
1968	10200	4100	147100	140100	1600	20300	-	1521	28500	1151800	-	-	-	**1505221**
1969	21400	3500	187758	113900	4000	14600	-	11401	31000	1183000	-	-	-	**1547601**
1970	39000	3700	247113	101900	300	12200	-	700	51800	1571600	700	-	-	**2011100**
1971	20100	3300	230586	68000	1200	16200	-	600	60500	1434400	700	-	-	**1835586**
1972	18200	2500	226486	64100	600	8900	-	200	64900	1489700	800	-	-	**1876386**
1973	21400	2400	157225	64800	400	17300	-	200	163800	1504400	800	-	-	**1932725**
1974	10829	5278	149031	33367	443	9166	-	532	173485	1771113	890	-	-	**2154134**
1975	6262	3273	176916	74476	496	9542	-	1939	170823	1644455	951	-	-	**2089133**
1976	8999	4759	158920	51851	330	4742	-	2033	326910	1380360	1051	-	-	**1939937**
1977	11068	4980	173609	157595	438	7361	-	8336	557334	1758715	721	-	-	**2680157**
1978	7858	6019	87158	201556	172	7055	-	25016	835958	2238781	2973	38	-	**3412584**
1979	6869	7808	108982	34902	233	10231	-	35767	741738	1922503	1377	-	-	**2870410**
1980	3989	8772	134456	16943	133	11384	-	34512	776792	1679126	1367	-	-	**2667453**
1981	1786	6279	116863	59425	1756	19305	-	43774	307858	1358257	2628	21	-	**1917952**
1982	2837	15636	144290	51733	467	34259	5	34364	344624	1176963	4286	36	-	**1809500**
1983	1749	10943	180034	64397	471	27017	10	34562	130884	1223717	900	309	102	**1675095**
1984	9945	12610	211750	36821	1106	71968	3	44614	501575	1331013	534	183	1247	**2223369**
1985	10080	29249	155785	31903	507	48903	138	46539	200792	1247348	545	126	6	**1771921**
1986	9555	33882	214925	31014	800	40719	-	49810	149132	1478708	975	562	-	**2010082**
1987	8662	39740	117569	36991	213	9948	1	46709	173770	1133360	622	206	424	**1568215**
1988	4423	38235	325890	18980	321	9635	-	51328	236250	1137728	863	1888	22	**1825563**

Table 9. (continued)

	FISHING AREA													
	Atlantic, Northeast	Mediterranean & Black Sea	Atlantic, Eastern Central	Atlantic, Southeast	Atlantic, Western Central	Atlantic, Southwest	Pacific, Northeast	Pacific, Eastern Central	Pacific, Southeast	Pacific, Northwest	Pacific, Western Central	Pacific, Southwest	Indian Ocean, Western	TOTAL
1989	6969	31710	313175	30216	606	13151	1470	60260	245107	981180	697	973	98	**1685612**
1990	9325	24058	171789	19925	1102	8966	10	77986	402365	673000	627	371	164	**1389688**
1991	10672	19615	140531	16614	380	11465	20	67650	293682	617564	1577	2135	-	**1181905**
1992	9165	26601	80205	4351	285	10038	785	38036	117635	668902	3344	2691	940	**962978**
1993	7728	31629	55614	4806	431	11836	30	31481	170849	1153494	4838	800	1	**1473537**
1994	5222	34481	104150	5321	401	15412	33	22206	99518	1234510	6605	630	32	**1528521**
1995	4717	28224	160377	5057	377	18737	1	11509	218026	109614	3307	433	-	**1546906**

species has occurred regularly although with considerable year-to-year variation (Baird, 1975). Chub mackerel represented about 2.6% (59.796 t) of total fish species landed in 1981 (Davila-Fernández, 1985). In the southeast Atlantic, catches reached a peak of 201 556 t in 1978 but decreased progressively to 5 057 in 1995 (Crawford, 1981b; Crawford & De-Villiers, 1984; FAO, 1997). Newman & Crawford (1980) and Crawford (1983) reported that species characterized by a greater longevity, such as pilchards, horse mackerel and chub mackerel, contribute little to the landings and a high fishing mortality on the younger ages maintains the parent populations at a low level. The chub mackerel populations of the southeast Atlantic are heavily exploited (FAO, 1992). The major chub mackerel fishing countries according to 1990 landings were South Africa (78.8%), the ex-USSR (10.2%), Spain (6.2%), Namibia (2.5%), and Israel (1.5%), followed by Germany, Japan, Romania, Korea and St. Helena, with less than 1% each (Stamatopoulos, 1993a) (Table11).

It is probable that chub mackerel populations of the western Central Atlantic (FAO Fishing Area 31) are intensely exploited in the majority of the fishing zones and overexploited in some of them. In the small West Indies, the insular countries have adopted a common criterion in order to promote the management of shared resources (FAO, 1992). The catch obtained in 1981 was 1 756 t, representing 0.1% of the total fish capture (Davila-Fernández, 1985; FAO, 1997), however this was much higher than the just over 300 t reported by Stamatopoulos (1993a). According to Stamatopoulos (1993a) and FAO (1997), catches of chub mackerel oscillated from 4 000 t in 1969 to 113 t in 1980 and 1 102 t in 1990 (Table 11). Major fishing countries according to 1990s production were Venezuela (80.4%), Guadeloupe (19.4%) and Mexico (Stamatopoulos, 1993a).

In Argentina, chub mackerel constitutes a very important resource particularly for the canning industry (Sánchez, 1982). In Brazil, Rijavec & Carvalho-Amaral (1977) reported that chub mackerel ranked second in importance after sardine (***Sardinella brasiliensis***). Catches in the southwest Atlantic (FAO Fishing Area 41) were 8 966 t in 1990, representing 0.51% of the total fish species landed in the area (Stamatopoulos, 1993a). The total catch of chub mackerel increased from 8 600 t caught in 1962 to 20 300 t in 1968, decreasing to 4 320 t in 1976, and progressively recovering until it reached 71 968 t in 1984. Subsequently, the fishery collapsed, obtaining a catch of 8 966 t in 1990, but during the first half of the 1990s it has shown signs of recovery, reaching 18 737 t in 1995 (FAO, 1997) (Table 11). Major fishing countries in this area according to 1990 production were Brazil (61.5%), Argentina (37.2%), Italy (1.0%), Uruguay and Germany (Stamatopoulos, 1993a).

Landings of chub mackerel in California have shown great variation between 1926 and 1978, with maximum catches from 1933 to 1944 and then progressively decreasing until 1978 (Parrish & MacCall, 1978; Schaefer, 1980; MacCall, 1983). Less than 20 t

Table 10. Catches of *Scomber japonicus* by country (in metric tons)

COUNTRY	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Algeria	-	-	-	-	-	-	-	-	-	-	-	-	-
Angola	2000	1100	2900	18000	15300	3500	800	200	2300	19700	21600	9400	1400
Argentina	14900	9700	8200	11600	9700	9900	16100	12100	16600	12100	9500	13800	6200
Benin	-	-	-	-	-	-	-	-	-	-	-	-	-
Brazil	200	200	400	1500	2100	1500	1300	3100	3100	2500	2700	2400	2700
Bulgaria	-	-	-	-	-	-	-	2274	2721	10321	16600	5700	3300
Cameroon	-	-	-	-	-	-	-	-	-	-	-	-	-
Chile	-	-	-	-	-	-	-	-	-	-	8000	8500	1000
China	80000	80000	84000	84000	84000	88000	88000	88000	92000	92000	173100	36600	78300
Côte d'Ivoire	-	-	-	-	-	-	-	341	2356	582	1064	37733	5241
Cuba	-	-	-	-	-	-	-	-	-	-	4800	400	200
Ecuador	-	-	-	3900	6600	7100	8100	8500	21300	23800	35000	41900	55200
Equatorial Guinea	-	100	100	200	200	-	-	-	200	200	200	200	200
Estonia	-	-	-	-	-	-	-	-	-	-	-	-	-
France	-	-	-	-	-	-	-	-	-	-	-	-	-
Gambia	-	-	126	-	-	-	-	-	-	-	-	-	-
Gaza Strip	-	-	35	143	20	120	50	70	-	-	-	-	-
Georgia	-	-	-	-	-	-	-	-	-	-	-	-	-
Germany/RDA	-	-	-	-	236	-	200	6200	2989	2394	19800	20521	1933
Ghana	800	2000	4000	5000	4000	15000	5062	16800	18500	6400	12100	14700	19100
Greece	1000	1000	1000	1000	1400	1300	800	1800	2100	1500	1000	1000	900
Guadeloupe	-	-	-	-	-	-	-	-	-	-	-	-	-
Iraq	-	-	-	-	-	-	-	-	-	-	-	-	-
Israel	-	-	-	-	-	-	-	-	300	100	400	200	300
Italy	-	-	-	-	-	-	-	-	-	-	-	-	-
Japan	351100	37800	408800	464900	495700	668900	624400	687500	1015300	1011400	1301900	1252700	1188300
Korea Rep.	2100	1800	4100	5400	2400	7300	2000	2800	10500	42100	38300	60600	79000
Latvia	-	-	-	-	-	-	-	-	-	-	-	-	-
Lebanon	-	-	-	-	-	-	-	-	-	-	-	-	-
Liberia	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.5
Libya	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithuania	-	-	-	-	-	-	-	-	-	-	-	-	-
Malaysia	-	-	-	-	-	-	-	-	-	-	-	-	-
Malta	0.5	0.5	100	100	0.5	0.5	0.5	0.5	100	100	100	100	0.5
Mauritania	-	-	-	-	-	-	-	-	-	-	-	-	-
Mexico	1700	4900	3200	8600	8800	7900	6000	1000	100	300	400	500	200
Morocco	5200	10300	9400	12554	7600	9900	9500	9500	7800	14000	30600	960	5100
Namibia	-	-	-	-	-	-	-	-	-	-	-	-	-
New Caledonia	-	-	-	-	-	-	-	-	-	-	-	-	-
Norway	-	-	-	-	-	-	-	-	-	-	5088	36786	5887
Oman	-	-	-	-	-	-	-	-	-	-	-	-	-
Panama	-	-	-	-	-	-	-	-	-	-	-	-	-
Peru	9400	11700	13300	7900	2000	3800	7600	13400	7200	7200	8800	10100	8700
Philippines	-	-	-	-	-	-	-	-	-	-	700	700	800
Poland	-	-	-	-	2696	2436	7461	8828	8558	6871	3118	3100	4700
Portugal	1900	5800	13100	6600	8600	30300	13100	16600	10400	21700	39300	20400	18400
Romania	-	-	-	-	700	1500	1600	3000	1200	3100	1700	4900	6726
Russia/ex-USSR	2400	3000	26500	36000	64500	27300	22200	41800	104500	158100	171000	195600	303100
Senegal	-	-	-	-	-	-	-	-	-	-	-	108	55
Slovenia	-	-	-	-	-	-	-	-	-	-	-	-	-
South Africa	31000	52300	21200	13400	52000	41000	54900	138900	91000	92800	77900	54600	56700
Spain	-	-	800	1400	1300	500	600	400	800	800	600	600	4200
St. Helena	-	-	-	-	-	-	-	-	-	-	-	-	-
Taiwan, Pr. China	8400	7700	7200	10900	16100	15900	13500	8600	19000	22200	28300	22600	18600
Togo	-	-	-	-	-	-	-	-	0.5	0.5	100	100	100
Timosoa	-	-	-	-	-	-	-	-	1000	800	900	700	600
Turkey	-	-	-	-	1000	1100	800	700	300	800	100	100	700
Ukraine	-	-	-	-	-	-	-	-	-	-	-	-	-
Uruguay	-	-	-	-	-	-	-	-	-	-	-	-	-
USA	17056	16696	20008	18254	12169	3198	2100	529	1421	1101	300	100	-
Vanuatu	-	-	-	-	-	-	-	-	-	-	-	-	-
Venezuela	-	-	-	-	200	400	300	400	1600	4000	300	1200	600
Yugoslavia	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 10. (continued)

COUNTRY	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Algeria	-	-	-	-	-	-	-	-	-	67	-	-
Angola	200	-	76	-	536	391	647	57	49	38	-	-
Argentina	12000	7800	8921	466	987	379	533	7645	1599	2124	5250	2577
Benin	-	-	-	-	-	-	-	-	-	-	-	-
Brazil	5300	1366	621	4258	6374	6675	9698	10620	17706	32117	2167	69391
Bulgaria	1323	1200	3598	6848	5303	2286	123	3516	2278	950	2552	39
Cameroon	-	-	-	-	-	-	-	-	-	-	-	-
Chile	3800	215	15235	50738	141263	182680	89117	102279	97457	20987	9280	111877
China	93100	113547	84487	78965	134852	282262	111637	83760	73466	107005	153932	123933
Cuba	-	-	-	492	300	240	262	2852	3239	2123	604	36
Ecuador	55000	110000	132000	236000	370000	550000	528623	570617	131862	257469	96527	291686
Equatorial Guinea	200	200	200	200	200	200	200	200	200	160	190	300
Estonia	-	-	-	-	-	-	-	-	-	-	-	-
France	-	-	-	-	-	-	-	1	-	-	18	170
Gambia	-	-	-	-	-	-	-	-	126	-	-	-
Gaza Strip	-	-	-	-	-	-	-	-	35	143	20	120
Georgia	-	-	-	-	-	-	-	-	-	-	-	-
Germany/RDA	-	-	-	-	164	898	8150	1844	1183	4462	1958	851
Ghana	10900	787	2699	604	452	538	97	224	363	67	241	739
Greece	900	917	1360	1911	1922	1942	1769	2183	2815	2898	4431	3899
Guadeloupe	-	-	-	-	-	-	-	-	1575	-	-	-
Iraq	-	-	-	-	-	-	-	7	3	-	-	-
Israel	300	152	159	191	199	142	145	227	267	338	182	284
Italy	-	-	-	-	322	15	-	598	565	-	22	179
Côte d'Ivoire	3513	217	84	1	-	6	-	84	35	9	3	20
Japan	1134000	1330501	1317967	978781	1354481	1625854	1491026	1300994	50778	717611	804797	813466
Korea Rep.	74200	80649	70123	107382	113051	99519	120283	62690	108082	99447	122883	101714
Latvia	-	-	-	-	-	-	-	-	-	-	-	-
Lebanon	-	-	-	-	-	-	-	-	-	-	-	-
Liberia	0.5	14	14	14	18	58	159	72	55	50	151	159
Libya	-	-	-	-	-	-	-	-	-	-	-	-
Lithuania	-	-	-	-	-	-	-	-	-	-	-	-
Malaysia	-	-	-	-	-	-	-	-	280	-	-	-
Malta	100	39	26	16	8	2	2	3	5	3	2	6
Mauritania	-	-	-	-	-	-	-	-	686	21	-	5
Mexico	100	471	1809	1863	3688	13876	9005	5179	3832	6134	1307	2245
Morocco	8800	21222	12279	26161	47573	47610	15676	31575	30362	56939	55125	130315
Namibia	-	-	-	-	-	-	-	-	-	-	-	-
New Caledonia	-	-	-	-	-	-	-	-	4	-	-	-
Norway	1926	-	-	-	-	-	-	-	-	-	-	-
Oman	-	-	-	-	-	-	-	-	-	-	-	-
Panama	-	-	-	-	-	-	-	-	-	-	-	-
Peru	65000	63270	23588	40172	46071	111505	108067	59062	42578	22072	22579	87134
Philippines	800	890	951	1051	721	2973	1224	1353	2628	4286	951	534
Poland	1800	2934	2478	7675	5646	2327	1122	695	1345	2285	1719	457
Portugal	21900	11157	6619	9414	11642	8746	7925	5335	2914	4112	2876	11005
Romania	6187	4986	9409	2462	5966	3109	2201	2133	3366	4349	2569	2835
Russia/ex-USSR	323400	364913	314507	375507	389507	445013	285930	365459	415290	433052	278976	372186
Senegal	47	100	3037	2998	3176	3593	2714	2381	2389	1721	4322	3473
Slovenia	-	-	-	-	-	-	-	-	-	-	-	-
South Africa	58800	30670	69344	545	21336	2443	11139	4213	10943	13643	13271	6962
Spain	2700	3543	4198	5950	4204	8951	15487	11230	8765	11383	7356	5009
St. Helena	-	42	38	29	20	41	33	33	35	33	12	33
Taiwan, Pr. China	8000	3137	3863	4369	8099	5144	5703	6436	14686	16290	19559	27015
Togo	100	83	117	150	179	179	37	244	129	238	49	167
Timosoa	1100	3574	1444	1281	1131	1597	2435	1951	3076	3386	2146	2515
Turkey	100	400	437	1323	1666	1610	3086	4338	4972	9011	4055	3009
Ukraine	-	-	-	-	-	-	-	-	-	-	-	-
Uruguay	-	-	-	-	-	-	-	-	-	-	-	-
USA	100	61	130	160	4648	11140	26762	29333	38535	28175	33075	42369
Vanuatu	-	-	-	-	-	-	-	-	-	-	-	-
Venezuela	400	443	496	330	438	172	233	111	181	467	471	1106
Yugoslavia	-	-	-	-	-	-	-	-	283	-	-	-

Table 10. (continued)

COUNTRY	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Algeria	-	-	-	-	-	-	-	-	-	-	-
Angola	-	-	-	-	-	-	-	-	-	-	-
Argentina	4393	4806	4197	4654	7966	3736	6236	4913	6689	10297	13442
Benin	120	369	434	428	519	519	527	344	373	419	406
Brazil	44510	45210	5697	4979	5104	5100	5214	5120	5100	5110	5290
Bulgaria	173	19	5	-	-	186	3361	-	-	-	-
Cameroon	-	-	-	-	-	-	-	-	3	3	4
Chile	11314	1584	32799	26423	39329	192948	191723	72364	96023	27171	110210
China	92573	132196	166039	240699	231625	196823	242639	243143	272605	336103	372050
Côte d'Ivoire	51	397	11	373	1084	1330	954	340	230	8	9
Cuba	244	172	175	64	6	2	-	-	-	-	-
Ecuador	114139	107470	116625	180347	145577	74473	61939	26322	45322	28232	63557
Equatorial Guinea	300	350	300	300	300	270	260	270	314	280	290
Estonia	-	-	-	15385	13030	8819	18185	1107	3390	692	2991
France	-	150	5	193	273	172	124	26	122	412	366
Gambia	-	-	-	-	-	-	-	-	-	-	-
Gaza Strip	50	70	-	-	-	-	-	-	-	-	-
Georgia	-	-	-	3052	3112	4379	1558	1315	1170	1107	1060
Germany/RDA	511	1068	466	169	402	1016	-	-	-	-	-
Ghana	164	20136	746	7604	13565	7654	23715	11982	4286	9769	12463
Greece	4071	3816	5011	3888	4326	3808	3995	5149	10996	14309	6469
Guadeloupe	-	-	-	-	-	-	-	-	-	-	-
Iraq	-	-	-	-	-	-	-	-	-	-	-
Israel	165	441	811	380	372	355	81	108	110	98	12
Italy	95	196	423	448	708	655	-	-	-	-	-
Japan	771901	944817	701405	648559	527485	273709	255157	269143	664678	633356	469805
Korea Rep.	68479	103887	101722	162841	163647	97232	91557	116425	174798	211233	200490
Latvia	-	-	-	23337	17788	22360	15685	3957	2614	4056	3494
Lebanon	-	-	-	-	-	-	-	-	-	-	-
Liberia	164	339	279	150	188	13	50	52	37	12	13
Libya	-	-	-	-	-	-	126	-	-	-	-
Lithuania	-	-	-	19650	14706	14953	12211	4240	1887	2357	-
Malaysia	-	-	-	-	-	-	-	-	-	-	-
Malta	11	9	1	1	3	3	3	10	10	10	13
Mauritania	144	4	9	33	30	30	30	30	30	30	32
Mexico	12107	11046	4183	5814	20003	40021	38941	19839	20608	12199	2903
Morocco	93278	101841	28589	37981	35574	27728	11128	15915	18311	39135	30106
Namibia	-	-	833	417	-	-	-	-	-	-	0.5
New Caledonia	-	-	-	-	-	-	-	-	-	-	-
Norway	-	-	-	-	-	-	-	-	-	-	-
Oman	-	-	7	-	-	-	-	-	-	-	-
Panama	-	-	-	-	-	-	-	-	-	212	-
Peru	87069	38709	24072	25554	32042	60776	17304	17939	29504	44115	44259
Philippines	537	965	612	863	697	627	1569	3344	4838	6605	3307
Poland	1785	344	550	-	-	-	-	-	-	-	-
Portugal	11546	10548	11005	5145	8115	10346	11335	9926	8838	5892	5210
Romania	4995	6253	6547	16742	7235	5975	5825	3003	67	-	-
Russia/ex-USSR	345868	363874	259140	252227	228314	104219	54302	24480	14427	29827	52706
Senegal	520	4454	7455	2023	1922	2498	1035	603	1394	1149	1748
Slovenia	-	-	-	-	-	-	-	2	1	4	3
South Africa	5498	4831	5637	7417	17966	14322	13435	4263	4722	4508	4677
Spain	5785	7310	3875	2929	3941	3941	-	-	-	-	-
St. Helena	18	17	28	24	18	23	13	9	7	8	7
Taiwan, Pr. China	29611	32371	30242	38811	33016	35978	22368	42728	41098	54904	54155
Togo	104	171	240	237	111	126	92	82	129	97	158
Timosoa	2376	2485	2464	2430	758	689	687	4910	3263	2333	2562
Turkey	22270	27410	31960	32280	26300	19150	14678	14762	15908	16748	17410
Ukraine	-	-	-	79899	37607	53408	17837	15421	7455	15205	66210
Uruguay	-	151	10	2	0.5	31	16	5	3	5	5
USA	34225	38757	42527	45514	40219	37975	28759	18982	10903	10040	8607
Vanuatu	-	-	-	-	-	-	-	-	54	-	-
Venezuela	507	800	213	321	606	1092	380	285	431	401	377
Yugoslavia	-	-	-	-	-	-	-	-	-	-	-

of chub mackerel were captured off central California from 1964 to 1968 (Parrish & Knaggs, 1972). The abundance of chub mackerel decreased substantially from 1983 and 1984 because of very weak recruitment (MacCall *et al.*, 1985), and subsequently the annual California landings have declined since 1988, when 42 220 t were landed. In 1996, the chub mackerel fishery took 10 284 t, slightly above the 19-year low of 8 666 t landed by the wetfish fleet in 1995 (Table 10). The increase in 1996 is largely attributable to a surge in landings during July, when large fish were readily available (Yaremko *et al.*, 1997). According to FAO (1992), the chub mackerel population in the eastern Central Pacific (FAO Fishing Area 77) is moderately exploited and the total annual catches have fluctuated from about 200 t in 1972 to 77 986 t in 1990 (FAO, 1992; Stamatopoulos, 1993b; FAO, 1997). Chub mackerel ranked fourth in 1990, representing about 5.85% of all species landed in Fishing Area 77. Major fishing countries in this region ranked according to their 1990 production were Mexico (51.32%) and USA (48.68%) (Stamatopoulos, 1993b).

Morales-Nin (1988) indicated that chub mackerel was the first species in catch volume in Ecuador, representing over 40% of the total pelagic species landed. According to Stamatopoulos (1993b), chub mackerel ranked fourth (2.93%; 402 365 t) in landings in the 1990 ranking for all species caught in the southeast Pacific (FAO Fishing Area 87). The 1960 catch of Chile, Peru and Ecuador was 9 400 t, increasing to 835 958 t in 1978. Subsequently, catches decreased progressively to about 99 518 t in 1994 (Stamatopoulos, 1993b; FAO, 1997). Claramunt-Quiñones & Fuenzalida-Fuenzalida (1989) reported that 150 000 t were caught during the 1982 fishing season off Ecuador, all of which was destined to the food industry. During the warm period of 1976-1984 the fishery was maintained except for the disruption caused by El Niño of 1982-1983 (Cubillos, 1989; Cañón, 1985; Stamatopoulos, 1993b). Chub mackerel represented 2.64% (176 771 t) of total fish landings in 1981 (Davila-Fernández, 1985), but the fishery entered a period of decadence after 1982 (Claramunt-Quiñones & Fuenzalida-Fuenzalida, 1989). In 1984, after the re-establishment of normal

Table 11. Catches of *Scomber japonicus* by FAO Fishing Areas (in metric tons)

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
1972	17940	221810	2239	64497	710	8636	474	53501	1477596	-	-	-	-
1973	21840	156570	2200	65300	475	17270	2978	163850	1343269	-	-	-	78
1974	10920	146134	3980	36270	390	11515	638	170530	1782070	-	-	-	150
1975	6240	176144	3184	74170	530	11803	2085	167192	1656700	-	-	-	40
1976	8580	156573	4775	52404	317	4320	2071	334383	1388045	-	-	-	54
1977	11232	172274	4935	197525	437	7770	7452	555076	1764160	-	-	-	46
1978	7800	87158	5570	201556	168	7200	27094	835958	2238781	-	-	-	35
1979	7020	110408	7959	37086	240	10360	35873	735640	1961172	-	-	-	-
1980	3989	135031	7960	16352	113	11384	34512	776792	1679126	-	-	-	-
1981	1240	123313	9551	58050	1757	18700	44295	317665	1343269	-	-	-	-
1982	2340	200239	15636	52404	460	34544	34313	374510	1208940	-	-	-	40
1983	1749	180056	10980	64375	471	27017	34625	134357	1223717	102	10	1001	309
1984	9945	212222	12734	36642	1106	71968	45230	501575	1331013	1247	3	534	183
1985	10080	165638	29447	31881	507	48903	46792	187255	1217348	6	138	545	126
1986	9405	215106	33740	30829	576	50167	48664	163848	1474465	-	-	975	562
1987	8580	117857	39794	36280	230	7700	46790	167200	1164165	-	-	-	235
1988	3900	326267	38200	20150	310	6910	51470	234070	1155210	-	-	-	1942
1986	7000	313595	31838	28217	600	12950	60830	250780	985063	-	-	-	971
1990	9346	172213	24672	19653	1102	8966	77986	402370	611744	164	-	-	371
1991	9360	137436	20307	20150	1085	8920	77675	401260	582080	-	-	-	388

oceanographic conditions, the catch increased to 501 575 t, but fell again to 149 132 t in 1986 (Stamatopoulos, 1993b; FAO, 1997). Maximum landings of mackerel in the north of Chile were recorded in 1977 and 1978 (141 263 and 182 680 t, respectively). In 1984, Chilean catches increased to former levels (over 100 000 t) then fell in 1986 to the lowest catches of the 1980s (1 584 t). Production rose progressively afterwards to reach a capture of 192 948 t and 191 723 t in 1990 and 1991 respectively (Díaz-Ocampo, 1991; FAO, 1997) (Table 11). Major fishing countries in this region ranked according to their 1990 production were Chile (47.37%), Ecuador (18.27%), ex-USSR (18.20%), Peru (14.91%) and Cuba (1.25%) (FAO, 1992; Stamatopoulos, 1993b).

The chub mackerel has been commercially important in the south-western Japan Sea and the East China Sea. This species accounted for more than 50% of the total catches of pelagic species exploited by the Japanese large type purse-seine fishery from 1973 to 1976 in the latter sea (Limbong *et al.*, 1991). In the northwest Pacific (FAO Fishing Area 61), chub mackerel ranked fifth, representing 2.97% (673 000 t) of the total catches (fish, molluscs and crustaceans) in 1990 (Stamatopoulos, 1993b). From 1960 to 1978, the fishery experimented a progressive increase in catch, reaching 2.2 million t in 1978, and subsequently decreased to 617 564 t in 1991. There was a gradual recovery toward 1994 when 1.2 million t were caught (FAO, 1992; Stamatopoulos, 1993b; FAO, 1997) (Table 11). In the southwestern Japan Sea and the East China Sea, the total catch of chub mackerel increased rapidly since 1969 with a peak in 1974. Thereafter, there was a gradual decrease in abundance (Iizuka & Hamasaki, 1983; Limbong *et al.*, 1991) and the stock was at a low level from 1984-1994 (Murayama *et al.*, 1995). Tanaka (1983) believes that the primary cause of stock variations was the success or failure of reproduction and the meandering of the Kuroshio current. Hirai *et al.* (1990) divided the temporal and spatial features of stock fluctuations in the coastal waters east of mainland Japan between 1967 and 1986 into 3 periods: good catch years (1967-1975), transition years (1976-1980), and poor catch years (1981-1986). Park (1984) reported that considering the continuous increase of annual growth of chub mackerel since 1977 (there was a significant negative correlation between population density and growth), the stock of Korean waters seemed to be overfished. Matsuda *et al.* (1996b) showed that the purse seine fishery consistently had a larger impact on the chub mackerel population than the dip-net fishery. This is because the proportion of immature fish caught by the purse-seine fishery was usually larger than that of the dip-net fishery. The number of individuals caught by the purse-seine net fishery was 66 times larger than in the dip-net fishery, such that the impact of the former was 84% that of the latter (Matsuda *et al.*, 1994). Major fishing countries in this region ranked according to their 1990 production were China (54.7%), Japan (23.9%), Korea (15.9%), Taiwan (4.6%), ex-USSR (0.73%) and Hong Kong (0.23%) (FAO, 1992; Stamatopoulos, 1993b).

In the western Central Pacific (FAO Fishing area 71), catches of chub mackerel increased from 700 t in 1970 to 4 286 t in 1982, but decreased to 627 t in 1990. Catches recovered again toward 1994 when 6 605 t were caught (Stamatopoulos, 1993b, FAO, 1997) (Table 11). In 1981, this species represented 0.06% (2.912 t) of the total fish landings in the region (Davila-Fernández, 1985).

The chub mackerel catch in the southwestern Pacific (FAO Fishing Area 81) was 21 t in 1981. The catch showed a progressive but strongly variable increase until a peak of 2 691 t was reached in 1992. Subsequently, the catch fell down to 433 t in 1995 (Davila-Fernández, 1985; Stamatopoulos, 1993b; FAO, 1997) (Table 11).

The Indian Ocean is the least fished ocean, probably because it is less productive and because the coastal countries have generally less-developed artisanal fleets. Catches are very variable, fluctuating from 1 247 t in 1984 to 6 t in 1985 (Stamatopoulos, 1993d; FAO, 1997) (Table 11). Ex-USSR commercial fisheries in Yemen waters were conducted in the northern Gulf of Aden since 1963. Fisheries were based mainly on chub mackerel. Total fish yield varied in the range from 30 000 to 40 000 t, with 60 to 70% of chub mackerel (Kukharev *et al*, 1993).

5.5 Climatic influences

D'yakov *et al.* (1984) distinguished that some hydrological events can be used as prognostic characteristics for catch prediction. Hagen & Weiss (1979) observed that large-scale upwelling in northwest Africa involves meso-scale variations caused by the action of continental shelf waves, which originates rhythmic variations in the oceanic environment, nutrient concentration, phytoplankton and zooplankton, and in catches of chub mackerel. Sedykh & Krivospichenko (1987) and Cury & Roy (1987) concluded that the emergence of strong year-classes is accompanied by weak upwelling, geomagnetic disturbances and smooth temperature curves. Binet (1982) reported that off the Côte d'Ivoire and Ghana, between approximately 1971 and 1978, a crisis of zooplankton biomass and a collapse of some coastal pelagic stocks (chub mackerel and ***Sardinella aurita***) appeared to have coincided with the Sahelian drought.

Some of the large-scale increases in recruitment off South Africa can be plausibly related to environmental factors. Thus, the exceptionally powerful 1966 cohort of chub mackerel was formed during a season in which the upwelling index was noticeably poor (Crawford, 1983), which could favour chub mackerel spawning (Shannon, 1976). Catches appear to be significantly related to cool sea-surface temperatures and northwesterly winds in the northern area. These responses may indicate the preferred habitat of the prey (cooler water temperatures) and/or availability of the resource to the fishing fleet (northwesterly winds push the upwelling front closer inshore) (Villacastin-Herrero, 1992).

Parrish & MacCall (1978) found that for the period 1931-1938 increased recruitment of chub mackerel was associated with increased sea-surface temperature, reduced sea level and reduced atmospheric pressure during the spawning season. This was in agreement with Sinclair *et al.* (1985), who reported that from 1928 to 1965 the higher survival rates to age-1 for chub mackerel in the California Current occurred during years of decreased southward transport, which in turn is related to El Niño events. During such years, plankton biomass was relatively low. Conversely, survival rates to age-1 were low during periods of increased southward transport, when plankton biomass was high. Sinclair *et al.* (1985) concluded that survival rates during the early life history might be more directly influenced by hydrographic processes than by biological interactions. Prager & MacCall (1993) also detected climatic influences on the reproductive success, which was usually high during conditions typical of ENSO events. A warm-water oceanic regime has dominated the California Current region for about 15 years, and Yaremko *et al.* (1997) speculate that this may have caused a northern migration of chub mackerel, particularly the older-year classes. The ecological effects of increased chub mackerel abundance in some years are confounded with other changes in the environment and fisheries. Chub mackerel extended its range far to the north during the 1980s, but the migratory effects of population pressure are difficult to separate from the influence of the strong 1982-1984 ocean warming. During the 1982-1984 ENSO, a large number of chub mackerel were reported in the west coast of Vancouver Island, Puget Sound and Queen Charlotte Sound (Canada), and were frequently caught off Oregon (MacCall *et al.*, 1985; Ashton *et al.*, 1985). The apparent northern migration with age may have been exaggerated in 1992-1993 because of another strong ENSO influence on sea-surface temperatures (Yaremko *et al.*, 1997).

In Peru, there was also a drastic decline in the landings of Peruvian anchovy (***Engraulis ringens***) in 1972, associated with ENSO and the intense fishing pressure (Jordán, 1983). This originated an important change in fish biomass and in the pelagic fish community structure. There was a very pronounced decrease in anchovy biomass (to approximately 1/10 of its original biomass), and an increment of 70% in the catches of sardine (***Sardinops sagax***), 81% in the catches of jack mackerel (***Trachurus symmetricus murphyi***) and 100% in the catches of chub mackerel (Jordán, 1983). On the other hand, Claramunt-Quiñones & Fuenzalida-Fuenzalida (1989) pointed out that in waters of Chile mackerel abundance did not show any correlation with environmental variables, nevertheless they found a light delay in reference to the maximum sea-surface temperature and atmospheric surface pressure.

Belyaev (1980b; 1985b) and Belyaev & Rygalov (1986) reported on a series of events which caused an increase in larval survival rates, and had a favourable effect on abundance of the year classes of 1975-1977. These events were higher water temperature on the spawning grounds, favourable distribution of eggs and larvae due to changes in the direction of the Kuroshio current, a southwestward shift of the meander and the predominance of westerly and southwesterly winds. Replacement of a dominant species among coastal pelagic fishes has occurred three times in Pacific waters along the northeastern Japanese coast since 1912. Peak Japanese sardine (***Sardinops melanosticta***) catches occurred in 1933, for Pacific saury (***Cololabis saira***) in 1958, for chub mackerel in 1970, and again for sardine in 1983. In terms of long-term fluctuations associated with oceanographic conditions, sardine dominates when the cold Oyashio Current departs from coastal waters to offshore waters along the Sanridu/Hokkaido coast. Chub mackerel dominates when the First Oyashio Intrusion is weak in comparison with the Second/Third Oyashio Intrusions. Pacific saury increases in years when sea-water temperature is high in the south but low in the north, even though the First/Second Oyashio Intrusion may be strong (Fukushima & Ogawa, 1988).

6. PROTECTION AND MANAGEMENT

Bottom trawling has been prohibited in False Bay (South Africa) since 1928 and purse-seine fishing is carried out since before 1960. Effort in the area increased after the collapse of the west coast pilchard (***Sardinops sagax***) and chub mackerel stocks in the late 1960s (Penney, 1991). Baird (1975) recommended that the annual catch should not exceed 80 000 t. In 1973, 1974 and 1975, the South African purse-seine fishing season was extended and additional quotas were granted specifically for the capture of adult chub mackerel. This does not appear to have been a wise move, and Crawford (1981a) recommended that it should not be repeated in the future. Crawford (1979) also noted that the smaller-mesh net used since 1965 resulted in a poorer yield per recruit for pilchard, round herring and chub mackerel, and recommended attempts to avoid catching juveniles of these species. Purse seining was prohibited in False Bay after 1982 (Penney, 1991). The International Commission for the southeast Atlantic Fisheries (ICSEAF) recommended a total catch of 200 000 t of chub mackerel between 1980 and 1985, and of 100 000 t in 1986-1987, in waters between 17°17' to 28°38'S and 10°00' to 20°00' E (ICSEAF, 1980; 1981; 1982; 1983; 1984; 1985; 1986; 1987).

The fishery of chub mackerel off California began in 1926. Due to a string of very strong year classes, abundance in the 1930s probably exceeded average virgin stock levels. Over the following years, spawning success (recruits per spawner) varied with a distinct six to seven year cycle which ended with the collapse of the resource around 1965. A moratorium on chub mackerel fishing was enacted by the State of California on 23 November 1970 (Knaggs, 1972; Klingbeil, 1983; MacCall, 1983). The norm AB 1732 provided that chub mackerel could not be taken commercially for two years. However, up to 18% (by weight) of any landing could consist of chub mackerel caught incidentally while fishing for other species (Knaggs, 1972; Schaefer, 1980; Klingbeil, 1983). In 1972, lawmakers extended the moratorium indefinitely and made provisions for a quota fishery should the stock recover (MacCall, 1983; Klingbeil, 1983). In 1972, a management scheme that set a quota on the chub mackerel landings became effective. Allocation depended on the spawning biomass estimated annually according to a harvest formula given in Section 8412 of the Fish and Game Code. The formula specifies that when the biomass is between 18 140 t and 136 050 t, the season's quota shall be 30% of the biomass in excess of 18 140 t. If total biomass is less than 18 140 t no directed landings are allowed, and if total biomass is greater than 136 050 t no limitation on total catch is imposed (MacCall, 1973; Schaefer, 1980; Yaremko *et al.*, 1997). During May 1977, the norm AB 1783 was introduced as emergency legislation for the purpose of relaxing the incidental catch provision of the moratorium law. In its final form, the new law increased the allowable incidental tolerance to 40% by weight and allowed for landings of "pure" loads of mackerel if they did not exceed 3 t. This law also stipulated that only pure loads and tonnages exceeding 18% of chub mackerel in mixed loads could be counted against any quota established for the 1977-1978 season, which was set at 5 000 t and subsequently increased to 9 300 t (Klingbeil, 1983). Once the quota was filled, regulations would revert to those dictated by the current law (18% incidental tolerance, and no pure loads until the following season). In July 1978, the norm AB 3704 was signed into law, establishing a different quota formula which called for a seasonal (1 October - 30 September) harvest equal to 20% of the total biomass in excess of 20 000 t. This law also provided that the California Department of Fish and Game could adjust the season's allowable catch quota, if an earlier determined biomass estimate was revised. It also established that the incidental catch of chub mackerel could not exceed 50% (by number) of the fish in any landing, and set daily limits for pure loads (Klingbeil, 1983). When the quota is opened, the allowable catch can be taken mixed or unmixed with other species (Schaefer, 1980). Additionally, a limit of 10 fish per day was placed on sport fishermen (Schaefer, 1980). During the late 1970s, the resource and the fishery began a rapid recovery. By 1979, the total biomass was estimated (Klingbeil, 1982) as approximately equivalent to the average biomass of 143 000 t, for the years 1937-43 (Parrish & MacCall, 1978).

There are no regulations for the chub mackerel fishery in Mexico (MacCall, 1979; Jacobson *et al.*, 1994), however, Green-Ruiz & Aguirre-Medina (1992) proposed 16 518 t as a maximum sustainable yield if mortality (Z) is 0.497 years^{-1}. Probably, there are also no regulations for Ecuador and Peru, although Jordán *et al* (1978), considering the total biomass of chub mackerel off Peru to be 1.9 million t recommended that the maximum catch for 1978 should not exceed 350 000 t. Serra (1983) reported that in Chile the use of purse seines with nets over 20 fathoms deep and a mesh size equal to or less than 38 mm was forbidden along a coastal fringe of one nautical mile. This law was proclaimed in order to protect the breeding areas.

Japanese domestic fishery regulations are very local in nature. Taken as a whole, they are very complicated and do not constitute a uniform policy (MacCall, 1979). Watanabe (1983) suggested that fishing should be limited whenever the stock is declining and recruitment is poor, within the allowable catches that correspond to minimum or safety levels of spawning magnitude (200 millions eggs). He suggested this firstly, to prevent any further deterioration of the stock, and secondly to ensure the stock to shift soon into the growing phase. Matsuda *et al.* (1992) concluded that harvesting policies of 1/5 constant rate of exploitation, prohibition of fishing when the stock is rare, and constant-escapement policy were effective for stock conservation. However, the abundance of the chub mackerel stock in the Pacific waters off northern Japan has decreased throughout the 1980s and is presently at a low level without any fishing regulation (Tokio *et al.* 1996). These authors proposed that 40% spawning biomass per recruit would be appropriate as a conservative threshold level for replacement, and also be acceptable as a target for management of the stock.

7. CULTURE

A considerable amount of research on the spawning and rearing of chub mackerel has been conducted by the U.S. National Marine Fisheries Service at the Southwest Fisheries Center, La Jolla, California. Chub mackerel eggs were hatched and reared to the age of 6 months, when the yield of the experiment was 31 130 kg/ha (Bardach *et al.*, 1972, quoted by Schaefer, 1980). Leong (1977) described the procedure used to induce spawning of male and female chub mackerel under laboratory conditions. Inoue *et al.* (1969), quoted by Schaefer, 1980, conducted experiments on the storage of sperm of chub mackerel by quick freezing for its use in artificial fertilization. Hunter & Kimbrell (1980) described the early life history of chub mackerel based on laboratory rearing studies.

8. REFERENCES

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Chub mackerel *(Scomber japonicus)* is a pelagic species which inhabits warm and temperate coastal waters of the Atlantic, Indian and Pacific Oceans. Chub mackerel undertake considerable seasonal migrations between feeding and spawning areas. The species reaches its fastest growth in length (between 35.4 and 62.6 percent of the maximum length of the species in each area) during the first year of life. The maximum reported age is 18 years. Spawning is normally limited to the first half of the year in the northern hemisphere, and to the second half in the southern hemisphere, but takes place all year round along the equator. Chub mackerel feed on zooplankton, although cephalopods and small pelagic fishes, especially anchovies and sardines, are also frequent in the diet. There is some evidence of cannibalism in this species. Chub mackerel are frequently preyed by tunas, marlins, sailfish, dolphin-fish, sharks, sea lions and sea birds. The species is of great importance for fisheries worldwide; in 1978, it ranked third in importance in catches by species (3.4 million tonnes), while in 1979 and 1980 it ranked fourth and fifth, with 2.8 and 2.6 million tonnes, respectively. In 1966, the species ranked fifth with a worldwide catch of 2.1 million tonnes. It is mainly caught with purse seines, sometimes using light, and also by trolling, lines, gillnets, traps, beach seines and midwater trawls.

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